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The Proceedings of

The 6th Kasetsart University Sriracha Campus International Conference (KU-IC 2024)

August 26, 2024 at Kasetsart University Sriracha Campus

"Sustainable Technology Economy and Management for Low-carbon Society"

The Proceedings of the 6th Kasetsart University Sriracha Campus International Conference (KU-IC 2024)

August 26, 2024

Subject: Engineering and Technology

Subject: Sciences and Applied Sciences

Subject: Economics and Applied Economics

Subject: Humanities and social sciences

Organized by

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In cooperation with

The Economic Association of Kasetsart University

The proceedings of

the 6th Kasetsart University Sriracha Campus

International Conference

August 26, 2024

Organized by

Kasetsart University Sriracha Campus

First Edition : August, 2024

Published by

Division of Research and Innovation

Administration, Office of Sriracha Campus,

Kasetsart University Sriracha Campus

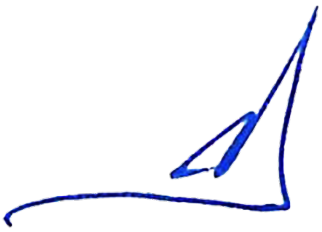
ISBN (e-book) : 978-616-278-857-4

Preface

Kasetsart University Sriracha Campus is pleased to announce the 6th Kasetsart University Sriracha Campus International Conference (KU - IC 2024) on "Sustainable Technology, Economy and Management for a Low-carbon Society." The conference will take place on August 26, 2024, at Kasetsart University's Sriracha Campus in Chonburi, Thailand. The goals are to provide a platform for undergraduate, master's, and doctoral students to present their research, facilitate the exchange of knowledge and experiences among attendees, present research findings on both national and international stages, and build networks that may lead to future collaborations and advancements in academia and research.

The conference will include oral presentations on selected themes vetted by renowned experts. These themes are classified into four groups: engineering and technology, science and applied science, economics and applied economics, and humanities and social sciences.

On behalf of the organizing committee for the 6th Kasetsart University Sriracha Campus International Conference (KU - IC 2024), we would like to thank the lecturers, researchers, academics, and students who are presenting their research findings, as well as those who are attending the conference. We also want to thank all of the committee members who donated their time, energy, dedication, and ideas to make the conference a success.



(Associate Professor Sathaporn Chuepeng, Ph.D.)
Vice President for Sriracha Campus
for Dr. Chongrak Wachrinrat
President
General chair of the conference

Conference Program

The 6th Kasetsart University Sriracha Campus International Conference (KU-IC)
"Sustainable Technology Economy and Management for Low-carbon Society"
August 26, 2024
Building 28, Faculty of Management. Kasetsart University Sriracha Campus

Time (Thailand Time)	Schedule of Activities			
12.30 - 13.00	Registration (Conference Room 28801, 8th floor)			
13.00 - 13.05	Report Statement by Mr. Natthapon Pannurat, Assistant to the President for Research, Social Missions, and Digital Sriracha Campus			
13.05 - 13.10	Welcoming Remarks by Assoc. Prof. Sathaporn CHUEPENG, Ph.D., Vice president for Sriracha Campus, Kasetsart University			
13.10 - 13.50	Keynote Speaker 1 : Professor Anand Marya, Ph.D., University of Puthisastra. Topic: "AI in Dentistry"			
13.50 - 14.30	Keynote Speaker 2 : Professor Makoto Ogawa, Ph.D., Vidyasirimedhi Institute of Science and Technology · School of Energy Science and Engineering. Topic: "Bionanocomposites for versatile applications"			
14.30 - 14.45	Coffee Break			
	Oral Presentation			
	Session 1 : Engineering and Technology (Room 28702, 7th floor) Session Chair : Professor Dr.Anand Marya Co-Chair : Mr. Siwakorn Sukprasertchai	Session 2 : Sciences and Applied Sciences (Room 28602, 6th floor) Session Chair : Assoc. Prof. Dr.Tongsai jamnongkan Co-Chair : Dr.Taddaow Khumpook	Session 3 : Economics and Applied Economics (Room 28603, 6th floor) Session Chair : Asst. Prof. Dr. Pat Pattanarangsun Co-Chair : Dr.Aekkapat Laksanacom	Session 4 : Humanities and social sciences (Room 28606, 6th floor) Session Chair : Asst. Prof. Dr.Nuthawut Sabsombat Co-Chair : Asst. Prof.Dr.Baweena Ruamchart
14.45 - 15.00	ID017	ID001	ID002	ID007
15.00 - 15.15	ID026	ID003	ID004	ID008
15.15 - 15.30	ID028	ID005	ID009	ID011
15.30 - 15.45	ID029	ID006	ID010	ID015
15.45 - 16.00	ID030	ID019	ID012	ID016
16.00 - 16.15	ID031	ID020	ID013	ID018
16.15 - 16.30	ID032	ID021	ID023	ID027
16.30 - 16.45	ID033	ID024	ID025	
16.45 - 17.00	ID034			
17.00 - 17.15	ID035			
17.15 - 17.30	ID036			
17.30 - 17.45	ID037			
18.00 - 22.00	Networking Night & Certificate Awarding Ceremony @ Holiday Inn & Suites Siracha Laemchabang			

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The 6th KU – IC

International Conference 2024

Subject :

Engineering and Technology

Non-Destructive Testing for Sediment Deposition in The Nam Sana Hydropower Plant Reservoir using Internet of Things

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Abstract
This study presents a method to monitor sediment deposition using the non-destructive testing (NDT) technique and the Internet of Things (IoT). The case study focuses on the Nam Sana Hydropower Plant reservoir in Laos. Sediment accumulation in hydropower reservoirs is a significant concern for plant efficiency. Traditional monitoring methods that rely on manual measurements lead to errors due to equipment limitations and human factors. This study demonstrates the feasibility and effectiveness of employing NDT with IoT systems to address these challenges. The proposed approach uses a 4–20 mA submersible water level sensor to collect sediment deposition data within the reservoir. An ESP32 microcontroller transmits this data and processes it using an A/D converter. The internet protocol used is the MQTT. By employing this technology, operators can approximate sedimentation trends. Data collection involves assessing multiple grid points within the reservoir area to optimize accuracy and efficiency. Calibration procedures included immersing the sensor in laboratory water to ensure accuracy, with results indicating an average accuracy of 98.5%. Using this calibrated method, the study calculated that the sediment volume in front of the dam in 2023 will be 4,554 cubic meters, representing 28.3% of the maximum water collected. Continuous sedimentation data collection facilitates proactive management strategies, thereby optimizing hydropower plant operations. This study concentrates on the feasibility of further innovation in the field to enhance the resilience and sustainability of hydropower plants.
Keywords: Sediment Deposition, Non-Destructive Testing (NDT) Technique, Internet of Things (IoT).

1. Introduction

The GDP of Laos PDR is predominantly driven by the production of hydropower plants. Currently, the annual total electricity production amounts to 51,031 GWh. This study focuses on the Nam Sana Hydropower Plant (NSN), located in Nasou Village, Kasi District, Vientiane Province, Lao PDR (see **Figure 1**). The NSN hydropower plant is equipped with three synchronous generators, with a total generation capacity of 14 MW approximately 49.5 GWh annually.

Damming a river creates a reservoir for hydroelectric plants, serving as controlled water storage facilities. The primary purpose of these reservoirs is to store water, which can be released as needed to run turbines and convert potential energy into mechanical and electrical energy, generating electricity on demand. Consequently, maximizing the operational efficiency of hydroelectric facilities should be a top priority. Effective water management impacts ecosystems [1] and is crucial for maintaining environmental balance and supplying water to businesses and households [2].

Figure 1 Location of Nam Sana Hydropower Plant

Sediment deposition refers to the accumulation of sand, clay, and other materials at the bottom of the dam reservoir. This can damage dam structures and various components, such as intake gates, tunnels, penstocks, and turbines, due to sediment erosion [3]. Additionally, sediment deposition can reduce the water storage capacity of reservoirs, leading to lower water levels. To mitigate these impacts, effective monitoring and management of sediment deposition are essential. Proper management can enhance electricity production and minimize the adverse effects on hydropower plants [4].

Sediment deposition monitoring in watersheds consists of various techniques for monitoring and assessing. Understanding sediment is essential, as it can affect the operation of hydropower plants. Typically, a variety of methods are used for monitoring, including remote sensing technologies, watershed surveys, and sediment sampling [5, 6]. These techniques help to identify areas of sediment deposition, predict future trends, and determine the amount and distribution of sediment.

Non-destructive testing (NDT) is crucial across all industries. Utilizing methods such as visual inspection, ultrasonic, radiographic, and magnetic particle testing, NDT significantly enhances the safety of structures and products by detecting defects early on [7]. These techniques are particularly important for monitoring the operation of hydropower plants, including turbines, oil pumps, penstocks, generators, stators, and dam structures, ensuring both efficiency and safety [8]. NDT inspections help reduce operational risks, equipment damage, and maintenance costs.

Internet of Things (IoT) system is a network of interconnected devices, sensors, software, and cloud services. This allows data to be collected, exchanged, and analyzed on the Internet. These devices are embedded sensors and communication capabilities. The connection could be Wi-Fi or a cellular network. These devices collect data, which is then processed and analyzed locally or on a cloud server[9-11]. This system can be used in a variety of fields, including agriculture, healthcare, and industrial automation. Data security is also a concern. The system guarantees the privacy and integrity of the shared information [12].

This study examines the implications of sediment deposition and the limitations of traditional monitoring techniques. It explores the potential of using NDT techniques integrated with IoT systems. The research aims to address the siltation problem at the Nam Sana Hydropower Plant, thereby supporting sustainable and efficient hydropower operations.

2. Existing System

The existing sediment deposition monitoring system at the Nam Sana hydropower plant reservoir is managed by the maintenance team. They utilize traditional field tape methods to measure 26 samples from a 1,210-square-meter area in front of the dam. These 26 grid points were selected based on a thorough examination of yearly data and calculations to determine sediment deposition amounts. Log sheets and annual inspections facilitate detailed analysis and assessment of sediment deposition.

Traditional sediment monitoring methods involve manual measurements, which can introduce errors due to suboptimal equipment, impacting data reliability and effective sediment management. To address these challenges, implementing IoT-based monitoring systems and precise NDT techniques can mitigate human error and enhance data collection processes. Additionally, real-time monitoring systems can improve sediment deposition management at hydropower plants (see **Figure 2**). **Figure 3** shows the yearly average sediment volume at Nam Sana Hydropower from 2015 to 2023.

Figure 2 Measuring the sediment deposition in the Nam Sana Hydropower Plant

It is calculated by the following equation.

$$V = (L \times W) \times H = m3 \quad (1)$$

Where V is the Sediment Volume (m3), L is the length of the Reservoir (m), W is the width of the Reservoir (m), and H is the thickness of sediment (m).

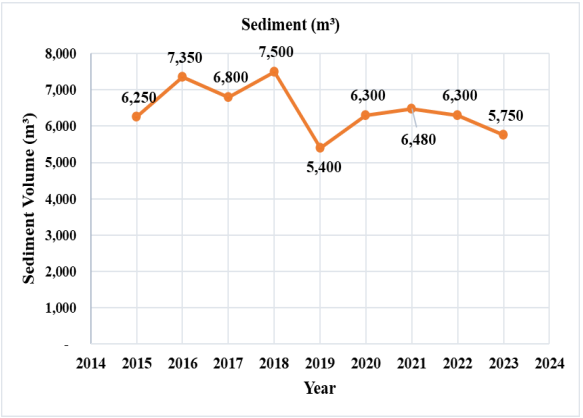

Figure 3 Sediment volume during 2015-2023

3. Model System

The method involves several steps to ensure seamless data processing and communication while establishing monitoring infrastructure. Firstly, the ESP32 microcontroller is connected to a rugged and adaptable 4-20 mA submersible IP68 sensor (water level sensor). The sensor data output is an electric current, which is transformed into electric voltage through the A/D. This conversion enables compatibility with the ESP32 and allows for further processing. Subsequently, the digitized sensor data is transmitted to a designated server using the ESP32's internet networking capabilities. This monitoring system accesses data through MQTT broker software such as Hive MQ, enabling device-to-device and data communication in IoT systems. This not only facilitates real-time data collection and analysis but also includes proactive decision-making and strategy. **Figure 4 and Figure 5**

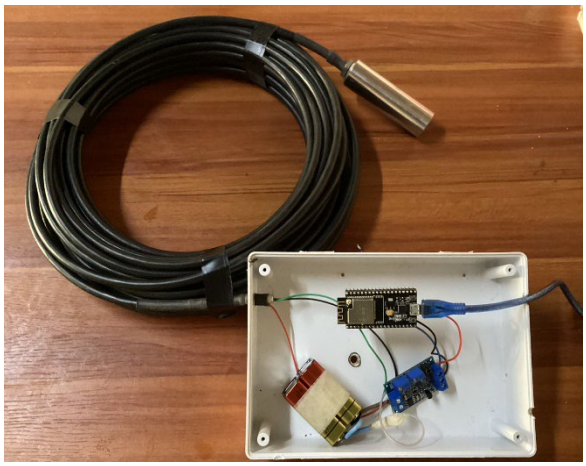

Figure 4 Model of the systems

3.1 Sensor

A 4-20 mA submersible IP68 sensor (water level sensor), a rugged and adaptable device, is used to measure parameters in submerged conditions. It transmits measurements via a 4–20 milliampere (mA) current. The data is measured between 4- 20 mA. Its IP68 rating ensures protection against dust and water ingress, making it ideal for various applications. It can measure parameters such as the level and pressure of

water [13]. Overall, it provides reliable and accurate data collection for industrial and environmental monitoring.

3.2 Power Supply

A battery is a power supply that stores chemical energy and transforms it into electrical energy. It consists of one or more electrochemical cells, with a positive electrode and a negative electrode in each cell. There are many types of batteries. Both disposable and rechargeable. They have different chemistries, such as lithium ions and lead acid. They provide power to electronic devices and vehicles. and storing renewable energy [14].

3.3 Converter

An electrical circuit known as a trans-impedance amplifier, or current-to-voltage converter (A/D converter) transforms an input current signal into an equivalent output voltage[15]. In sensor interface and measuring systems, where the output of a current-producing sensor needs to be converted to a voltage signal for additional processing, this kind of converter is frequently employed in many applications.

3.4 Microcontroller

The ESP32 is a multi-purpose microcontroller with built-in WiFi, Bluetooth, and internet connectivity. This makes it suitable for IoT systems. It uses Low power consumption for efficiency. The ESP32 can use a rich set of interfaces for connecting sensors and devices. It can be programmed using various, such as Arduino IDE, ESP-IDF, Micro Python, or Lua. With support for a wide range of communication protocols, ESP32 is widely used in applications. various smart homes smart cities, and smart farms until industrial control [16].

3.5 Broker

Hive MQ is a unique MQTT broker, enabling efficient communication between devices on the IoT. MQTT is a real-time messaging protocol that works well in low-bandwidth situations. or unstable connectivity, Hive MQ is an excellent choice for managing MQTT-based communications because it is scalable and reliable. Hive MQ's security features message and enable seamless integration across a wide range of industries. It enables real-time data exchange and promotes the smooth operation of IoT systems [17].

3.6 Server

A computer server or cloud server refers to a specialized computer system or software application that provides services, resources, or functionalities to other computers, known as clients, within a network. Servers play a crucial role in facilitating communication, data storage, and resource sharing across a network [18].

3.7 Monitoring

Monitoring refers to the process of observing, tracking, and analyzing the performance, behavior, and health of systems, networks, applications, or devices over time [19]. The primary goal of monitoring is to ensure the availability, reliability, and optimal performance of IT infrastructure and services.

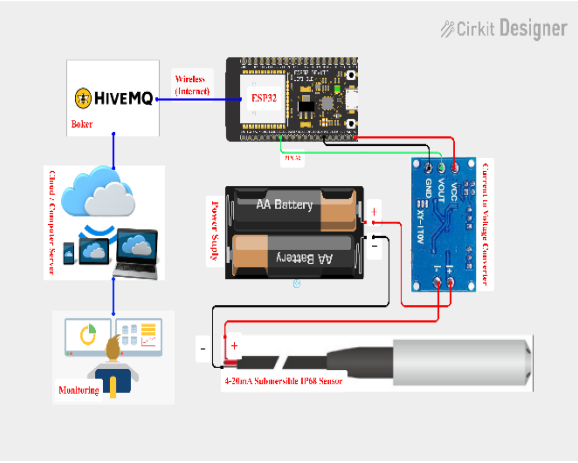

Figure 5 Diagram of the systems

4. Implementation System

4.1 Sensor Calibration

Before starting to collect data using the technique, it is important to perform a calibration procedure to confirm the accuracy of the sensor reading, reduce the potential

error in data collection, and increase the reliability of the system. The sensor standard specifies the error value at 3 levels. **Table 1**. This thorough calibration process immerses the sensor in water in the laboratory to a water depth of 2000 mm five times. Following this, the sensor data is compared to the real depth. From the calibration of the sensor's accuracy, the sensor can measure the depth of the reservoir, and the average accuracy is up to 98.5%. **Table 2.**

Table 1 Sensor Error Value

No.	Water Deep (mm)	Error Value (%)
1	1,000 – 2,000	2.0
2	3,000 – 5,000	1.0
3	6,000 – 10,000	0.5

Table 2 Sensor Calibration

No.	Water Deep (mm)	Data Sensor (mm)	Accuracy (%)
1	2,000	1,968	98.4
2	2,000	1,978	98.8
3	2,000	1,986	99.3
4	2,000	1,958	97.9
5	2,000	1,964	98.2
Average	2,000	1,970	98.5

4.2 Data Collection

The data collection process for this system involves collecting data from 26 samples within the dam front. These 26 samples were identified based on annual analysis and historical data collection. Additionally, comparisons will be made between the data collected from 18, 26, 36, and 52 grid points. These grid points are within an area of 1,210 square meters to find the grid points covering to collect the data. This comparative analysis aims to pinpoint the most effective number sample of points for capturing accurate and representative data, thus refining the overall data collection methodology. **Figure 6, 7, 8, 9.**

After obtaining the water depth value from the water sensor, the data can be used to calculate the thickness of the sediment and the volume of sediment accumulation in the reservoir according to the following mathematical equation:

The equation for calculating the sediment thickness within a reservoir.

$$H = h_1 - h_2 = m \quad (2)$$

Where H is the thickness of the Sediment Deposition (m), h_1 is the water's real level in the Reservoir (m), and h_2 is the water level in the Reservoir from the Sensor (m).

The equation for calculating the volume of sediment within a reservoir.

$$V = (L \times W) \times H = m^3 \quad (1)$$

Figure 6 Data Collection 18 Grid Points

Figure 7 Data Collection 26 Grid Points

Figure 8 Data Collection 36 Grid Points

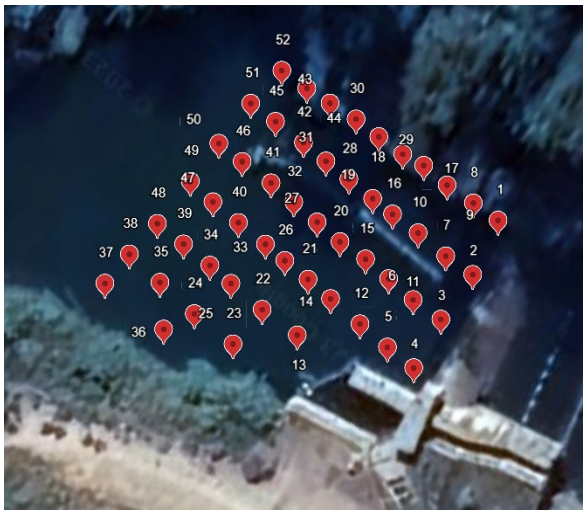

Figure 9 Data Collection 52 Grid Points

5. Results and Discussion

The study on the Nam Sana reservoir demonstrates the effectiveness of NDT techniques and IoT systems for sediment deposition monitoring. Real-time data collection offers valuable insights for reservoir management. The IoT monitoring system efficiently gathers continuous data, providing real-time information on sediment deposition and environmental conditions. High-resolution sensors detect sedimentation hotspots, enabling proactive management strategies. Overall, the integration of IoT systems and NDT techniques proves essential for enhancing sediment monitoring and guiding decisions about sediment deposition management and environmental preservation at the Nam Sana reservoir.

Devices installed within the reservoir consistently measure sediment levels and transmit this information to Hive MQ using the MQTT protocol. This allows operators or monitoring systems to promptly access real-time sediment deposition data, ensuring timely and accurate monitoring (see **Figure 10).**

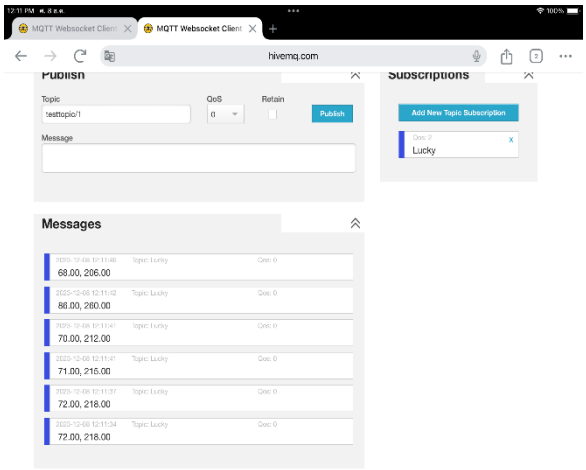

Figure 10 Access this data through Hive MQ

The sediment deposition data will be collected from four sample sets of water reservoirs varying in sample sets, with 18, 26, 36, and 52 grid points, respectively. **Table 3.** The objective is to identify the sample set that yields efficiency. Comparative analysis determined that the dataset comprising 36 samples sufficed for computing the sediment volume in front of the dam. **Figure 11**. This assessment enables the evaluation of impacts and efficient management of sediment deposition, consequently enhancing the hydroelectric power plant's operational efficiency

Table 3 Data collection grid points

No.	Data Collection Point	Sediment Volume (m^3)
1	18	4,263
2	26	4,410
3	36	4,554
4	52	4,549
Average		4.444

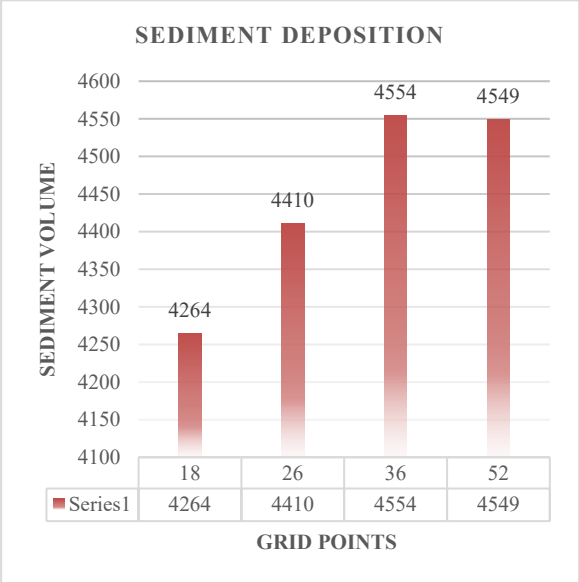

Figure 11: Data Comparing

In collecting data on sediment accumulation in the reservoir, we will determine the area to collect data. We will conduct data collection in 4 sets, where each set of data sets has a different grid point, such as 18, 26, 36, and 52, and bring sensors to be installed to collect data according to the points set. The determination of this point is based on the existing system, and random sampling has been added to compare the data set that can be covered throughout the reservoir area.

6. Conclusion

The study provides evidence for the effectiveness of integrating NDT techniques with IoT-based technology to quantify sediment deposition in the Nam Sana hydroelectric reservoir. The IoT system comprises a monitoring interface, 4 -20 mA submersible water level sensor, A/D converter, ESP32 microcontroller, and MQTT broker with a cloud server. These components efficiently collect and process measurements, making real-time sediment data accessible to operators through the monitoring system. This facilitates well-informed decisions regarding reservoir planning and enhances usability.

Data obtained through the proposed method illustrate sediment accumulation in the front dam reservoir. The water level sensor is first calibrated in the laboratory using the water depth technique, achieving an accuracy of 98.5%. The front dam area covers 1,210 square meters, with 36 data grid points identified as sufficient for accurately calculating sediment quantity and managing sediment deposition. Using this methodology, it was determined that the volume of sediment accumulated during the 2023 rainy season was 4,554 cubic meters, corresponding to 28.3% of the overall water collection.

Acknowledgement

The authors sincerely thank the Electricity Generating Authority of Thailand (EGAT), Electricité du Laos (EDL), and EDL-Generation Public Company (EDL-GEN) for granting access to hydropower plant data and facilities, which greatly facilitated this research.

Reference

[1] Y. M. Meskr, A. K. Mohammed, A. T. Ayalew, and T. K. Lohani, "Multi-purpose reservoir operation concomitant with estimating hydropower potential using multifarious hydrological models," *Heliyon,* vol. 10, no. 1, p. e23821, 2024/01/15/ 2024, doi: https://doi.org/10.1016/j.heliyon.2023.e23821.

[2] S. Daneshgar and R. Zahedi, "Investigating the hydropower plants production and profitability using system dynamics approach," *Journal of Energy Storage,* vol. 46, p. 103919, 2022/02/01/ 2022, doi: https://doi.org/10.1016/j.est.2021.103919.

[3] P. W. Castro, "Sediment management at the water intake of hydropower plants," *Arabian Journal of Geosciences,* vol. 15, no. 12, p. 1118, 2022.

[4] F.-Z. Lee, J.-S. Lai, and T. Sumi, "Reservoir Sediment Management and Downstream River Impacts for Sustainable Water Resources—Case

Study of Shihmen Reservoir," *Water,* vol. 14, no. 3, p. 479, 2022. [Online]. Available: https://www.mdpi.com/2073-4441/14/3/479.

[5] M. M. Al-Mamari *et al.*, "Assessment of sediment yield and deposition in a dry reservoir using field observations, RUSLE and remote sensing: Wadi Assarin, Oman," *Journal of Hydrology,* vol. 617, p. 128982, 2023.

[6] N. Mrozińska, M. Habel, and K. Obolewski, "The effects of sediment types on the structure of bottom invertebrate communities in a small European lowland dam reservoir," *Ecohydrology & Hydrobiology,* 2023.

[7] M. Opačić, A. Sedmak, G. Bakić, N. Milošević, and N. Milovanovic, "Application of advanced NDT methods to assess structural integrity of pressure vessel welded joints," *Procedia Structural Integrity,* vol. 42, pp. 1185-1189, 2022.

[8] M. E. Bajgholi, G. Rousseau, M. Viens, D. Thibault, and M. Gagnon, "Reliability assessment of non-destructive testing (NDT) for the inspection of weld joints in the hydroelectric turbine industry," *The International Journal of Advanced Manufacturing Technology,* vol. 128, no. 9-10, pp. 4223-4233, 2023.

[9] Z. F. Sumarna, N. Sartika, L. Kamelia, A. E. Setiawan, and T. Yusuf, "Implementation of Micro Hydro Power Plant Monitoring System Based on Internet of Things," in *2023 9th International Conference on Wireless and Telematics (ICWT)*, 2023: IEEE, pp. 1-5.

[10] E. H. Fort *et al.*, "Wireless and Low-Power System for Synchronous and Real-Time Structural-Damage Assessment," *IEEE Sensors Journal,* vol. 23, no. 12, pp. 13648-13658, 2023, doi: 10.1109/JSEN.2023.3270961.

[11] A. Promwungkwa, "Evaluation of the Long-Term Utilization of the Internet of Things in a Batch-Type Ceramics Kiln," *International Journal of Science and Business,* vol. 26, no. 1, pp. 155-163, 2023.

[12] A. S. Adiwarman, R. R. Pahlevi, and H. H. Nuha, "Microhydro Power Plants with IoT-based Monitoring and Prediction using Linear Regression," in *2023 International Conference on Artificial Intelligence, Blockchain, Cloud Computing, and Data Analytics (ICoABCD)*, 2023: IEEE, pp. 7-12.

[13] C. L. Faria, M. S. Martins, T. Matos, R. Lima, J. M. Miranda, and L. M. Gonçalves, "Underwater energy harvesting to extend operation time of submersible sensors," *Sensors,* vol. 22, no. 4, p. 1341, 2022.

[14] S. Clark *et al.*, "Toward a unified description of battery data," *Advanced Energy Materials,* vol. 12, no. 17, p. 2102702, 2022.

[15] D. Karimjonov, I. Siddikov, S. Azamov, and R. Uzakov, "Study on determination of an asynchronous motor's reactive power by the current-to-voltage converter," in *IOP Conference Series: Earth and Environmental Science*, 2023, vol. 1142, no. 1: IOP Publishing, p. 012023.

[16] D. Hercog, T. Lerher, M. Truntič, and O. Težak, "Design and Implementation of ESP32-Based IoT Devices," *Sensors,* vol. 23, no. 15, p. 6739, 2023.

[17] B. Mishra, B. Mishra, and A. Kertesz, "Stress-testing MQTT brokers: A comparative analysis of performance measurements," *Energies,* vol. 14, no. 18, p. 5817, 2021.

[18] L. Lina, "Application Analysis and Development Strategy of Cloud Computing Technology in Computer Data Processing," in *2023 International Conference on Distributed Computing and Electrical Circuits and Electronics (ICDCECE)*, 29-30 April 2023 2023,

pp. 1-7, doi: 10.1109/ICDCECE57866.2023.10150519.

[19] A. Albița and D. Selișteanu, "A Compact IIoT System for Remote Monitoring and Control of a Micro Hydropower Plant," *Sensors,* vol. 23, no. 4, p. 1784, 2023.

Life Cycle Assessment of an Air Conditioner Insulated Pipe Production

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Abstract

The objective of this research is to present a Life Cycle Assessment of the air conditioner insulated pipe production process. The process under study is the Cradle-to-Gate. The activities include inbound transportation, acquisition of raw materials, production processes and scrap disposal. For the environmental impact analysis, the IPCC GWP 100a method is used to determine the occurrence of global warming and CO_2 emissions. The ECO indicator 99 method is applied to investigate the impact characterization of human health, ecosystem quality and resource usage. The impact assessment uses the SimaPro 7.3.2. The results show that the copper pipe assembly has the highest value of CO_2 equivalent at 7067418.2 kg CO_2. So, this research attempts to reduce the environmental impact by using aluminium pipes instead of copper pipes. It was found that the CO_2 equivalent was reduced to 1550486.3 kg CO_2. In addition, the results from ECO indicator 99 for all 11 measurement indexes found that the use of aluminium pipes has a lower impact on human health, ecosystem quality and resource usage than copper pipes.

Keywords: air conditioner insulated pipes, Life Cycle Assessment, CO_2 emission

1. Introduction

An air conditioner is a type of electrical appliance used to adjust the temperature in a room that needs to be cooled or stabilized. The components of an air conditioner are as follows: 1) Compressor: a part where the refrigerant has a higher temperature and pressure 2) Condenser: a part that extracts heat from the refrigerant. The refrigerant will flow through the expansion valve 3) Evaporator: the function is to absorb heat to the refrigerant at constant pressure and 4) Throttling device: a part used to reduce the pressure and temperature of refrigerants by changing the refrigerant state to a gas state. The insulated pipe of the air conditioner is made from a special type of elastomer. The internal structure consists of copper pipes, insulation sheets, foam, and pipe caps. The basic properties of the insulated pipe are to protect the air conditioner system against heat and humidity.

The production process for insulated pipe consists of forming a plastic pipe, cutting insulation panels, assembling plastic pipes with insulation, inserting copper pipes and aluminium pipes into plastic pipes, and then the end cap will be assembled. These production processes use raw materials such as metal and plastic including energy from machines.

The production processes release carbon dioxide resulting in environmental problems in the production area. The manufacturing company focuses on sustainable practices and has an environmental policy with the goal of selecting appropriate raw materials to reduce environmental problems and reduce energy consumption. Then, the life cycle assessment is used to analyze carbon dioxide emissions in

production lines.

Life Cycle Assessment (LCA) is a systematic analysis and quantitative tool used to evaluate the potential environmental impacts throughout the entire life cycle of products or services. The life cycle of products includes raw material extraction, manufacturing processes, transportation and distribution, usage and waste treatment [1-2].

The research mentioned about the Life Cycle Assessment in the air conditioner industry is as follows. Research shown in [3] presented that more environmentally friendly refrigerants were found to be suitable alternatives for commercial refrigeration and residential air conditioning systems. The Life Cycle Assessment by using a solar absorption cooling system was proposed in [4]. The paper proposed in [5] presented that different materials or different technologies should be changed for air conditioners to protect the environment and human health. In [6], the operation phase of the air conditioner system seems to have the highest environmental impact, then, a 100% clean electricity power system should be considered. Those researches show that air conditioning system components have an impact on the environment.

This research proposes the Life Cycle Assessment of the insulated pipe production process for air conditioners. the IPCC GWP 100a method and ECO indicator 99 method were used to analyze the environmental impact. The comparison of raw materials between copper and aluminium is shown in the results. The life cycle of the product includes the acquisition of raw materials, production, transportation, usage and waste treatment.

2. Life Cycle Assessment [7-11]

2.1 Definition of Life Cycle Assessment

Life Cycle Assessment (LCA) is the approach used to analyze and evaluate the environmental impact of products and services in various industrial fields. The assessment of environmental impact is mostly to investigate the consumption of raw materials and energy including wastes for the production processes. The categories of the Life Cycle Assessment are as follows:

- Gate to Gate: the scope of the study is only production processes
- Cradle to Gate: the life cycle of a product starts from raw materials extraction to the end of production processes
- Cradle to Grave: the life cycle of a product starts from raw materials extraction to the usage and disposal of residues
- Cradle to Cradle: this is a type of Cradle to Grave including the recycling process

2.2 Life cycle assessment tools

SimaPro packaged program is a science-based tool for Life Cycle Assessment according to the International Organization for Standardization (ISO). The software functions include the impact assessment methods, inventory and Input/output databases and parameters/scenario analysis. The software is widely used in industrial problems and applications. The examples are the carbon footprint, water footprinting and biodiversity assessments.

2.3 Impact Index

2.3.1 IPCC 2007 GWP 100a

The Intergovernmental Panel on Climate Change (IPCC) Global Warming Potential (GWP 100a) is the issue of climate change established in 1988 by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO). The issue refers to GWP values calculated over 100 years. The IPCC acts as a measure of the environmental impact that may happen from global climate change.

2.3.1 Eco-Indicator 99

The Ecological Index (Eco-indicator) is an environmental assessment method that provides a numerical value or score based on the life cycle inventory of products. The indicator is used to assess the ecosystems and the impact of human activities. A higher value of the indicator means a greater severity of environmental impact.

The characteristics of an Eco-Indicator are as follows.

1. Raw materials, energy and waste have 11 impact categories.
2. All 11 impact categories are grouped into 3 groups according to the characteristics of the target group.
3. Weighting or combining scores into a single score.

The damages to human health are expressed in units of DALYs, which are the number of years of health loss. This index is proposed by the World Bank and WHO concerning the respiratory effects and carcinogens.

The impact of climate change depletion of the ozone layer and radiation on human health consists of the following topics.

1. Carcinogenic substances
2. Respiration of organic substances
3. Respiration of inorganic substances
4. Radiation substances (Radiation)
5. Climate change
6. Ozone depletion
7. Acidity (Acidification) / Eutrophication (Eutrophication)
8. Ecotoxicity
9. Use of space (Land use)
10. Use of minerals (Mineral)
11. Use of fossil fuels (Fossil fuel)

3. Research Methodology

This research proposes the Life Cycle Assessment to determine the carbon dioxide emissions of the insulated pipe production processes for air conditioners. The case study company is an air conditioner manufacturer. The company policy aims to reduce the amount of carbon dioxide released from the production processes according to ISO 14040.

3.1 Goal and scope of the study

The goal and scope of the study are to evaluate the carbon dioxide emissions of insulated pipes of air conditioning systems. The production processes, which is a system boundary are shown in Figure 1.

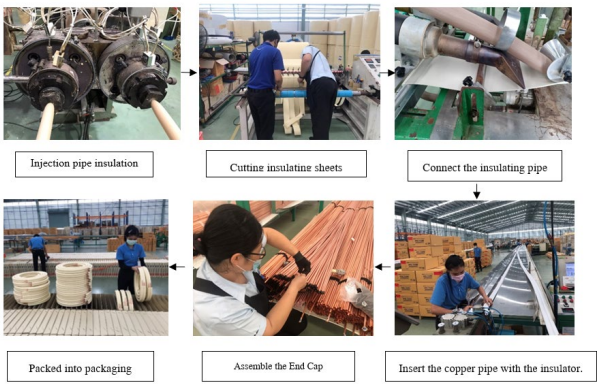

Figure 1 The system boundary

3.2 Analysis of environmental inventory (Data Inventory analysis)

The Data Inventory analysis is the step to collect the data according to the ISO14041 standard. The production processes comprise 1) the injection of pipe insulation 2) the cutting process of insulating sheets 3) the connection of the insulating pipe 4) the insertion of the copper pipe into the insulator 5) the assembly of the end cap and 6) the packaging process.

The step of Data Inventory analysis is to calculate the number of incoming inputs (raw materials, resources and energy) and outgoing outputs (products, co-products and waste). Table 1 shows the incoming inputs and Table 2 shows the outgoing outputs of insulated pipe from the case study company.

Table 1 the number of incoming substances (Input) including raw materials, resources and energy

Input	Quantity	Unit
Raw material		
Plastic LDPE	50,352.00	KG
Insulation panels	88,032.90	KG
plastic pipe	41,232.71	KG
Copper pipe	1,489,337.11	KG
End Cap	1,791.52	KG
Cardboard box	375,866.82	KG
Resources and materials to help production		
Electricity, light bulbs + electrical machinery	34,385.62	kWh
BUTANE GAS(C4H10)50KG.	6,800.00	kg

Table 2 the number of outgoing substances (Output) including raw materials, resources and energy

Output	Quantity	Unit
Products on the way to the next process		
Plastic pipe	41,232.71	KG
Insulation sheet	83,070.02	KG
Assemble insulation with plastic pipe	103,064.90	KG
Assembly of copper pipes	1,592,402.01	KG
Insulation pipe products	1,955,097.85	KG
Scrap		
Scrap plastic pipe	9,119.29	KG
Insulation sheet scraps	4,962.88	KG
Plastic pipe scraps covered with insulating sheets	21,237.83	KG
cardboard scraps	22.89	KG

The functional unit is a kilogram of insulated pipe.

3.3 Environmental Impact Assessment

This research evaluates the environmental impacts of the production process of insulated pipes for air conditioning systems, resource usage information and the release of waste throughout the production process using the program SimaPro Version 7.3.2. The IPCC GWP 100a and Eco-Indicator 99 methods are applied to assess environmental impacts by dividing impacts into 2 groups:

1. Global warming (Global Warming): the amount of carbon dioxide released by using the IPCC GWP 100a method.
2. Damage to human health, DALY units, using the Eco-Indicator 99 method.

3.4 Interpreting the assessment

The interpretation of the assessment is followed by the ISO14042 standard.

4. Results

4.1 Evaluation of carbon dioxide emissions throughout the cycle

The quantity of carbon dioxide emissions from the production process of insulated pipes of air conditioning systems is shown in Table 3.

Table 3 Quantity of carbon dioxide emissions from the production process of insulated pipes of air conditioning systems.

Impact Category	Total	%	Unit
Copper	7067418.2	90.3	kg CO2 eq
Combine tube and Insulator	604791.99	7.73	kg CO2 eq
Endcap HDPE	5992.3836	0.0766	kg CO2 eq
Packaging final insulation	144612.39	1.85	kg CO2 eq

From the analysis using the IPCC 2007 GWP 100a method, the process that has the highest impact on carbon dioxide emissions is the copper pipe assembly process. The other significant processes are the raw materials acquisition, smelting, melting, heating, and forming.

4.2 Environmental impact assessment throughout the life cycle of insulated pipes of air conditioning systems

Table 4 Quantity of 11 impact categories by using Copper assembled

Damage category	Impact category	Total	Unit
Human Health	Carcinogens	0.77299	DALY
	Respiratory organics	0.0169	DALY
	Respiratory inorganics	49.7692	DALY
	Climate change	1.643	DALY
	Radiation	0.0117	DALY
	Ozone layer	0.0011	DALY
Ecosystem Quality	Ecotoxicity	36067297	PAF* m2yr
	Acidification/ Eutrophication	961206	PAF* m2yr
	Land use	121429	PAF* m2yr
Resources	Minerals	69499139	MJ surplus
	Fossil fuels	6556998	MJ surplus

Table 4 shows the quantity of 11 impact categories using copper as a raw material. The depletion value of minerals resources is 69498259.25 MJ surplus. The value of ecotoxicity 35960682.59 PAF*m2yr because the acquisition of copper as a mineral requires mining, sifting, and smelting. It has the highest impact on the ecosystem compared to various production processes. The assembly process also has a high impact on all indices by the Eco-indicator 99.

4.3 Analysis of environmental impacts from the amount of carbon dioxide released after the renovation.

From the evaluation of the carbon dioxide emissions, the result shows that the assembly process of 1 kilogram copper pipes has the highest amount of carbon dioxide. From the IPCC 2007 GWP 100a evaluation method, the CO_2 emission is 7067418.2 kg CO2 eq. From the ECO - indicator 99 method, the assembly process of copper pipes has the highest overall impact. The result shows that the Ecotoxicity is 35960682.59 PAF*m2yr and the depletion of mineral resources is 69498259.25 MJ surplus. Therefore, the processes need to be improved. The engineering design concept will be applied to reduce energy usage and increase organizational efficiency. The new product design is required by changing the new type of raw material.

The research proposes the use of an alternative raw material, which is an aluminium pipe. The expectation of the research is the reduction of energy consumption and environmental impact compared with copper. Aluminium is three times lighter, cheaper and more biodegradable than copper. Using aluminium pipe also increases the image and stability of the organization because of the price of raw materials and product performance.

Table 5 shows the comparison of carbon dioxide emissions between copper and aluminium for insulated pipes.

Table 5 the comparison of carbon dioxide emissions between copper and aluminium insulated pipe

Impact category	Total	Unit
Copper	7822815	kg CO2 eq
Aluminium	2305883.1	kg CO2 eq

The production of insulated pipes for air conditioning systems by using aluminium pipe will release carbon dioxide only 2305883.1 kg CO2 eq, which is less than products using copper pipes (releasing carbon dioxide gas up to 7822815 kg CO2 eq). Using the aluminium pipe can reduce the carbon dioxide emission by approximately 70%.

4.2 Environmental impact assessment throughout the life cycle of insulated pipes of air conditioning systems after the renovation

Table 6 the comparison of 11 impact categories between copper and aluminium insulated pipe

Impact category	Copper Total	Aluminum Total	Unit
Carcinogens	0.77299	0.3743	DALY
Respiratory organics	0.0169	0.0031	DALY
Respiratory inorganics	49.7692	1.6027	DALY
Climate change	1.643	0.4779	DALY
Radiation	0.0117	0.00399	DALY
Ozone layer	0.0011	0.00068	DALY
Ecotoxicity	36067297	1108262	PAF*m 2yr
Acidification/ Eutrophicatio n	961206	33074	PAF*m 2yr
Land use	121429	32492	PAF*m 2yr
Minerals	69499139	348162	MJ surplus
Fossil fuels	6556998	2604860	MJ surplus

From Table 6, the results are as follows.
-Damage to human health group, life cycle assessment results for each production process for producing insulated pipes for air conditioning systems per 1 kilogram. Health is 1771767.3 Pt. Total environmental impact is greater than that of aluminum pipe. It has a

health impact value of 83639.715 Pt, reduced by 95 percent, which consists of Carcinogenic substances (Carcinogenic) Respiration,Radiation,Global warming (Climate change), Depletion of the ozone layer (Ozone depletion)

- Group of impacts on the existence of the environment (Damage to Ecosystem quality). The results of the study found that the production of insulated pipes of air conditioning systems per 1 kilogram in the three impact groups, functional unit (Pt), copper pipe assembly process has an impact value of Health is at 409850.57Pt, affecting the existence of the environment. rather than consisting of aluminum pipes. The environmental impact value was 15416.754 Pt, reduced by 96 percent.

These include Acidity/abnormal algae growth. (Acidification/Eutrophication), Toxicity (Ecotoxicity), Space use (Land use)

-Damage to Resource depletion group

The results of the study found that production of insulated pipes for air conditioning systems per 1 kilogram in three impact groups, functional unit (Pt), copper pipe assembly process had a health impact value of 2719767.5 Pt, affecting resources. rather than consisting of aluminum pipes The resource impact value was 105600.12Pt, reduced by 96 percent, which consisted of: Use of minerals (Mineral), Use of fuel (Fossil fuel)

5. Conclusion

The results from this research can be concluded as follows. The amount of carbon dioxide emissions generated from the production of insulated pipes of air conditioning systems using the IPCC 2007 GWP 100a method is 7822815 kilograms of carbon dioxide equivalent. The copper pipe assembly process has the highest carbon dioxide emissions at 7067418.2 kilograms of carbon dioxide equivalent. and has the lowest value of product packaging at 144612.39 kg CO2 equivalent.

The environmental impact that arises from the production of insulated pipes of air conditioning systems by ECO Indicator 99 method shows that the assembly of copper pipes has the highest overall impact on the environment. The reduction of mineral resources is at 69498259.2457204 MJ surplus due to naturally occurring inorganic elements or composites.

In the case of aluminium pipes, the amount of carbon dioxide emissions by using the IPCC 2007 GWP 100a method is 2305883.1 kilograms of carbon dioxide equivalent. The aluminium pipe assembly process emits the most carbon dioxide at 1550486.3 kilograms of carbon dioxide equivalent, or 67.2%, compared to all processes. If compared with copper pipes which have a much higher carbon dioxide release, accounting for 90.3% compared to all processes.

The environmental impact that arises from the production of insulated pipes for air conditioning systems by the ECO Indicator 99 method found that the assembly process of copper pipes has a higher overall environmental impact than the aluminium pipes.

Reference

[1] Ralph K. Rosenbaum and Stig Irving Olsen. 2018. Life Cycle Assessment: Theory and Practice 1st Edition., Springer, Cham, Switzerland.

[2] Walter Klöpffer and Birgit Grahl. 2014. Life Cycle Assessment (LCA): A Guide to Best Practice 1st Edition., Wiley, Weinheim, Germany.

[3] Mohamed Beshr, Vikrant Aute, Omar Abdelaziz, Brian Fricke and Reinhard Radermacher. 2017. Potential Emission Savings from Refrigeration and Air Conditioning Systems by using Low GWP Refrigerants, International Journal of Life Cycle Assessment, Volume 22, p. 675-682.

[4] Lígia da Costa Garcia, Dener Delmiro Martins, Rafaela Ramos

Barbosa and Monica Carvalho. 2021. Greenhouse Gas Emissions Associated with Two Air-Conditioning Systems for a University Building, Environmental Challenges, Volume 5, p. 1-8.

[5] Selim Karkour, Tomohiko Ihara, Tadahiro Kuwayama, Kazuki Yamaguchi and Norihiro Itsubo. 2021. Life Cycle Assessment of Residential Air Conditioners Considering the Benefits of Their Use: A Case Study in Indonesia, Energies, Volume 14 No. 2, p. 1-18.

[6] Jaqueline Litardo, David Gomez, Andrea Boero, Ruben Hidalgo-Leon, Guillermo Soriano and Angel D. Ramirez. 2023. Air-Conditioning Life Cycle Assessment Research: A Review of the Methodology, Environmental Impacts, and Areas of Future Improvement, Volume 296,
p. 1-20.

[7] Matthew John Franchetti , Defne Apul .2012. Carbon Footprint Analysis: Concepts, Methods, Implementation, and Case Studies (Systems Innovation Book Series) 1st Edition., Ohio, America

[8] Mike Berners-Lee .2022.The Carbon Footprint of Everything., Lancaster, England

[9] Mike Berners-Lee .2023.The Power of Life Cycle Assessment: Data Driven Decision Making for Environmental Sustainability., America

[10] Matthias Finkbeiner.2016. Special Types of Life Cycle Assessment (LCA Compendium – The Complete World of Life Cycle Assessment) 1st Edition., Kindle Edition., Frankfurt am Main, Germany

[11] Kathrina Simonen .2014. Life Cycle Assessment (PocketArchitecture) 1st Edition., Newyork, America

Unknown Input Thrust Estimation using Extended Kalman Filter for a Sounding Rocket

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Abstract
The emergence of smaller satellites and environmental concerns have driven the need for miniaturized sounding rocket development. A successful mission requires a guidance, navigation, and control (GN&C) system, with navigation being crucial for state estimation and feedback control. While larger launch vehicles can leverage extensive measurement inputs for state estimation, small-scale vehicles face significant challenges in this regard. The absence of an input would affect the effectiveness of state control. To address this, Unknown Input Extended Kalman Filter (UIEKF) has been proposed in past researches. The UIEKF follows the framework of the standard Extended Kalman Filter (EKF) but differs by considering the unknown input (UI) as one of its states and using available measurements to estimate the UI. This paper aims to make use of UIEKF to estimate the unknown thrust of a rocket and evaluate its performance through simulation in MATLAB/Simulink. Only the longitudinal direction is subjected to study. The non-linear longitudinal state equation of sounding rocket is presented. The rocket use fins at the side to control the orientation of the rocket in pitch direction. A simple approach to modify EKF for unknown input estimation is proposed. The estimated states using EKF and UIEKF is compared. The study examines three different thrust curves to assess the effectiveness of the UIEKF in various scenarios. The results of the estimated thrust are also illustrated.
Keywords: Sounding Rocket, State Estimation, UIEKF, Thrust

1. Introduction

As we step forward into the modern edge of space exploration called NewSpace, the tendency toward a reusable and eco-friendly launch vehicle has been emphasized and encouraged in order to reduce the earth's carbon footprint [1]. This shift has redirected research interests towards small satellites and low-cost rockets, which play a pivotal role in this new standard [2].

Guidance, navigation, and control (GN&C) is used to ensure that the rocket is robust to uncertainties and capable of maintaining its desired flight path. One of the crucial parts of the system is navigation, which uses input from external sensors to calculate and predict the internal state of the rocket. This can be used to let the controller know and correct itself by sending the control signal to the actuator. However, the reliability and accuracy of navigation can be compromised if sensor input is absent.

Accurate thrust estimation during flight is critical for the success of flight missions, as it directly impacts trajectory control, fuel efficiency, and mission safety. However, real-time thrust estimation presents significant challenges due to the complex dynamics and uncertainties inherent in rocket propulsion systems. Previous studies done by [3], [4], introduced the unknown input estimation for linear and non-linear system, respectively, showing promise in handling unknown inputs (UI) and uncertainties in dynamic systems. The studies lead to various application in power system, structural engineering, and vehicle [5], [6], [7]. Yet none of the mentioned paper has been done on a high accelerate vehicle such as the rocket yet.

The main objective of this research is

aimed to develop a UIEKF framework for state estimation with and without UI estimation, validate its performance through simulations using MATLAB/ Simulink environment with multiple thrust profiles, and compare its effectiveness against existing method and the actual state.

2. Methodology

2.1 State-Space Model

The state model is used to present the non-linear differential equations of the system as first-order to simplify the complexity [8]. In this paper, only the longitudinal direction of the rocket (shown in Figure 1) will be studied.

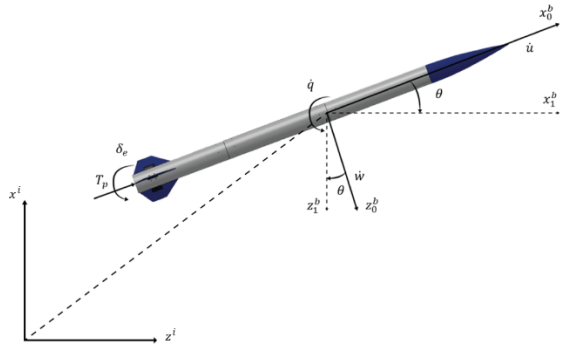

Figure 1 longitudinal direction axes and states variable of a sounding rocket.

Only the components in $x-axis$ and $z-axis$ are subjected to be studied. All the state in lateral direction is considered to be zero. The state variables and its description are listed in Table 1. On the other hand, there exist two inputs for the rocket. The known input, δ_e or u_1, which is the input angle of the rocket fin deflection angle and, T_p or u_2, the thrust of the rocket which is the unknown input of this study.

Table 1 State variables in longitudinal direction

State Variables	Description
u	Linear velocity along x^b
w	Linear velocity along z^b
q	Pitch rate
θ	Pitch angle
h	Altitude from x^i to x^b

The non-linear state equations in longitudinal as well as the aerodynamic coefficients are adapted from [9]. The equations are then converted into state equations where the states (u, w, q, θ, h) rewritten as $(x_1, x_2, x_3, x_4, x_5)$ respectively, as the follow,

$$\begin{aligned}\dot{x_1} = &-x_3x_2 - g\sin(x_4) \\ &+\left(\frac{\rho V^2 S}{2m}\right)\left(C_{X_0} \right. \\ &\left.+ C_{X_\alpha}\alpha + C_{X_{\delta_e}}u_1\right) \\ &+\left(\frac{\rho VS}{4m}\right)C_{X_q}cx_3 \\ &+\frac{u_2}{m},\end{aligned} \tag{2}$$

$$\begin{aligned}\dot{x_2} = &\,x_3x_1 + g\cos(x_4) \\ &+\left(\frac{\rho V^2 S}{2m}\right)\left(C_{Z_0} \right. \\ &\left.+ C_{Z_\alpha}\alpha + C_{Z_{\delta_e}}u_1\right) \\ &+\left(\frac{\rho VS}{4m}\right)C_{Z_q}cx_3,\end{aligned} \tag{3}$$

$$\begin{aligned}\dot{x_3} = &\left(\frac{\rho V^2 cS}{2J_y}\right)\left(C_{m_0} + C_{m_\alpha}\alpha \right. \\ &\left.+ C_{m_{\delta_e}}u_1\right) \\ &+\left(\frac{\rho VSc^2}{4J_y}\right)C_{m_q}x_3,\end{aligned} \tag{1}$$

$$\dot{x_4} = x_3, \tag{4}$$

$$\dot{x_5} = x_1\sin(x_4) + x_2\cos(x_4), \tag{5}$$

where:

- c = Mean aerodynamic chord of wing.
- g = Gravitational acceleration, m/s^2.
- m = Rocket mass, kg.
- ρ = Density of air, kg/m^3.
- S = Surface area of wing, m^3.
- $C_{X_0}, C_{X_\alpha}, C_{X_{\delta_e}}$ = Aerodynamic force coefficient along the body frame $x-axis$.
- $C_{Z_0}, C_{Z_\alpha}, C_{Z_{\delta_e}}$ = Aerodynamic force coefficient along the body frame $z-$

$axis$.

- $C_{m_0}, C_{m_\alpha}, C_{m_{\delta_e}}$ = Aerodynamic pitching moment coefficient.
- J_y = the inertia matrix along $y - axis$.
- $V = \sqrt{x_1^2 + x_2^2}$.
- $\alpha = \text{atan}^2\left(\frac{x_2}{x_1}\right)$.

Hence, after applying Euler-Maruyama approximation the state equation and measurement equation of the rocket can be written as,

$$x_k = f_d(x_{k-1}, u_{k-1}) + \sqrt{Q_{k-1}} v_{k-1},$$

$$y_k = h(x_k, u_k) + \sqrt{R_k} w_k,$$

where $x_{k-1} = (x_1, x_2, x_3, x_4, x_5)_{k-1}{}^T$ is the state variable at time $k-1$. y_k is the measurement vector at time k. u_{k-1} is the input. While w_k and v_{k-1} are the random Gaussian noise, they represent the process noises and measurement noises. The model process noise Q_k and model measurement noise R_k are $1 \times 10^{-6} \cdot I_{5\times1}$ and 1×10^{-3}, respectively. f and h are the non-linear state function contained equations (1), (2), (3), (4), (5).

2.2 Extended Kalman Filter (EKF)

The Kalman Filter (KF) is a type of filter that operates effectively in scenarios where the dynamics of the observed phenomenon are linear. However, KF is not applicable for non-linear system. Hence, a variant of KF called Extended Kalman Filter was proposed. Like KF, EKF consists of two computation phases, the prediction and measurement update. EKF equations can be written as follow,

Prediction

$$\hat{x}_{k|k-1} = f_d(\hat{x}_{k-1|k-1}, u_{k-1}),$$

$$A_{k-1} = \left.\frac{\partial f_d}{\partial x}\right|_{x=\hat{x}_{k-1|k-1}, u_{k-1}},$$

$$P_{k|k-1} = A_{k-1} P_{k-1|k-1} A_{k-1}^T + Q_{k-1}.$$

Measurement

$$W_k = P_{k|k-1} C^T \left(C P_{k|k-1} C^T + R_k\right)^{-1},$$

$$\hat{x}_{k|k} = \hat{x}_{k|k-1} + W_k\left(y_k - \hat{y}_{k|k-1}\right),$$

$$P_{k|k} = P_{k|k-1} - W_k C_k P_{k|k-1}.$$

The proposed rocket model consisted of 3 measurement inputs. The linear velocity u and pitch angle θ are assumed to be measurable through Inertial Measurement Unit (IMU) sensor. The altitude h is to be calculated and measured using barometer sensor. Thus, the measurement matrix become,

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix}.$$

The initial state $\hat{x}_{k|k-1}$ and initial error covariance $P_{k|k-1}$ of EKF are initialized as $0.1 \times \text{N}(0, I_{5\times1})$ and $0.01 \times I_{5\times1}$, respectively. The measurement noise of EKF, Q_{k-1} is $1 \times 10^{-4} \cdot I_{5\times1}$, while the process noise, R_k is $1 \times 10^{-4} \cdot I_{5\times1}$.

2.3 Unknown Input Extended Kalman Filter (UIEKF)

UIEKF follows the framework of EKF. The unknown input (UI) can be estimated if it considered as one of the states. Therefore, the state vector of UIEKF can be written as,

$$x = [x_1, x_2, x_3, x_4, x_5, d]^T$$

where d is the unknown input. Let $u_2 = d$. Then, UIEKF can be written as,

Prediction

$$\begin{bmatrix} \hat{x}_{k|k-1} \\ \hat{d}_{k|k-1} \end{bmatrix} = f_d(\hat{x}_{k-1|k-1}, u_{k-1}, \hat{d}_{k-1|k-1}), \qquad (6)$$

$$A_k = \left.\frac{\partial f_d}{\partial x}\right|_{x=\hat{x}_{k-1|k-1},u_{k-1},\hat{d}_{k-1|k-1}}, \quad (7)$$

$$P_{k|k-1} = A_{k-1}P_{k-1|k-1}A_{k-1}^T + Q_{k-1}. \quad (8)$$

Measurement

$$W_k = P_{k|k-1}C^T\left(CP_{k|k-1}C^T + R_k\right)^{-1}, \quad (9)$$

$$\begin{bmatrix}\hat{x}_{k|k}\\ \hat{d}_{k|k}\end{bmatrix} = \begin{bmatrix}\hat{x}_{k|k-1}\\ \hat{d}_{k|k-1}\end{bmatrix} + W_k\left(y_k - \hat{y}_{k|k-1}\right), \quad (10)$$

$$P_{k|k} = P_{k|k-1} - W_kC_kP_{k|k-1}. \quad (11)$$

The initial state $\hat{x}_{k|k-1}$ and initial error covariance $P_{k|k-1}$ of UIEKF are initialized as $0.1 \times \mathrm{N}(0, I_{6\times1})$ and $0.01 \times I_{6\times1}$, respectively. On the other hand, the measurement noise of EKF, Q_{k-1} is $1 \times 10^{-4} \cdot [1,1,1,1,1,2\times10^3]$, while the process noise, R_k is $1 \times 10^{-4} \cdot [1,1,1,1,1,4\times10^4]$.

2.4 Simulation Setup

MATLAB/Simulink software were selected for the simulation. The sampling time is $0.001\ s$ and the initial parameter for EKF and UIEKF and noises are randomly generated. The thrust curve (Figure 8, Figure 9, Figure 10) for the simulation is calculated using Richard Nakka's solid rocket motor software [10]. Three motors classes are selected, class F, H, and I.

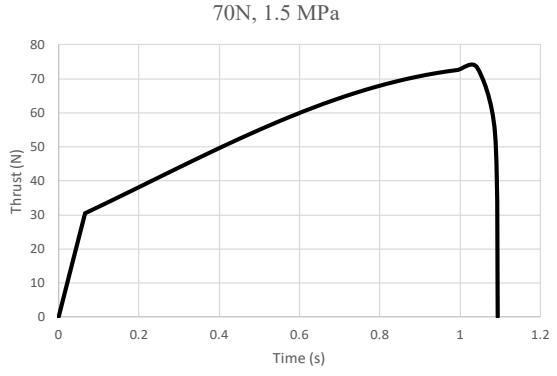

Figure 2 70N rocket thrust curve, class F.

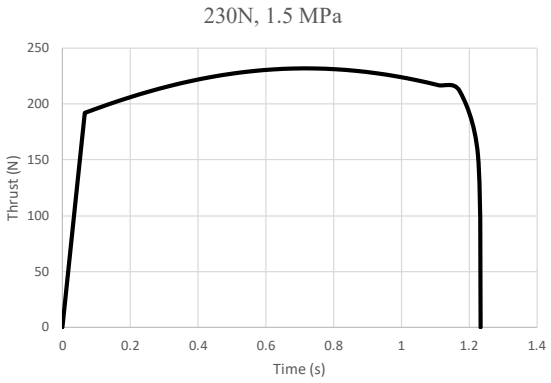

Figure 3 230N rocket thrust curve, class H.

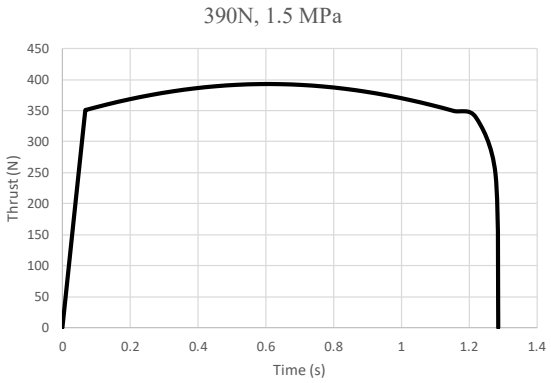

Figure 4 390N rocket thrust curve, class I.

Figure 5 and Figure 6 illustrate the integration of EKF and UIEKF in MATLAB Simulink. In this simulation, EKF estimates the state of the rocket without the UI estimation while UIEKF has to estimate both the state and UI. The largest thrust was chosen for the simulation because it has the longest thrust time, making it easier to analyze the results.

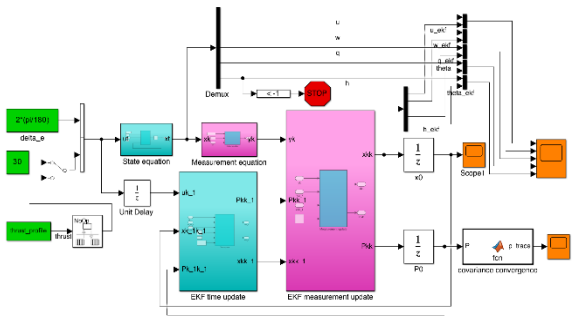

Figure 5 Simulink schematic for state estimation using EKF.

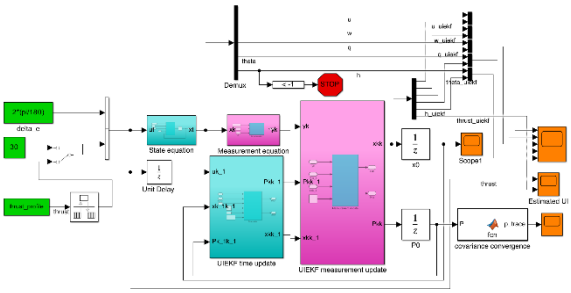

Figure 6 Simulink schematic for state and UI estimation using UIEKF.

3. Result and Discussion

To illustrate the performance of both EKF and UIEK clearly, is presented. Overall, UIEKF has better performance in estimating the state of the rocket compared to EKF. First of all, Both UI and EKF has the greatest estimation in altitude. Both algorithms were able to estimate accurately the altitude throughout the simulation. As for the linear velocity u, although it seems like both fairly estimated the state, the UIEKF outperformed EKF since it was able to estimate precisely without any state error from the initial state to the end. On the other side, both algorithms showed instability and error in estimating the linear velocity w and pitch rate q, yet UIEKF shown a better result due to its smaller state error and smaller setting time compared to EKF. Finally, for the estimation of pitch angle θ, EKF shows a large fluctuation at the beginning. While UIEKF become stable around $0.14s$, EKF remain unstable until $1.3\ s$. Although, both contained noises. The reason why EKF has the same performance after $1.3\ s$ is because the unknown thrust input is no longer present in the system. Therefore, both UIEKF and EKF work on the same model after rocket thrust is no longer relevant.

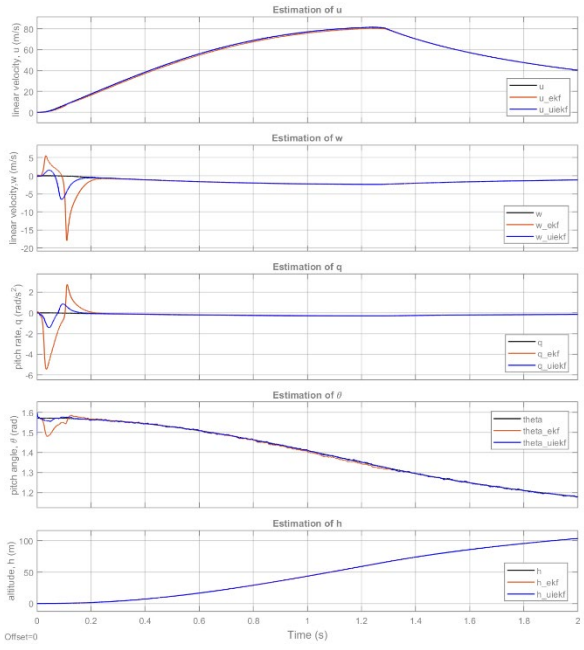

Figure 7 Result comparison of state estimation using EKF and UIEKF with 390N thrust.

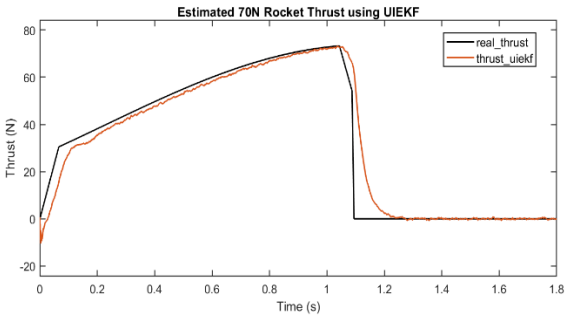

Figure 8 Estimated 70N thrust using UIEKF.

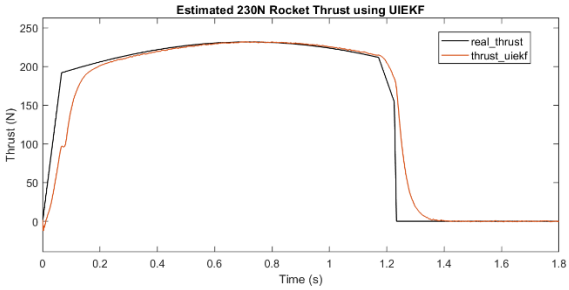

Figure 9 Estimated 230N thrust using UIEKF.

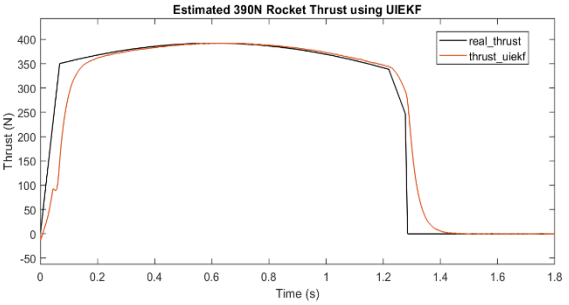

Figure 10 Estimated 390N thrust using UIEKF.

Table 2 Statistical analysis of the estimation error.

States	Est.	Mean Error	Standard Deviation	RMSE	ANOVA		Significance
					F	p-value	
u	EKF	3.67E-05	5.81E-01	9.36E-01	29959.26	0	YES
	UIEKF	1.02E-06	4.84E-02	5.25E-02			
w	EKF	2.13E-05	1.73E+00	1.78E+00	309.70	4.61E-69	YES
	UIEKF	9.20E-06	9.05E-01	9.23E-01			
q	EKF	8.70E-06	6.77E-01	6.99E-01	744.39	2.1E-162	YES
	UIEKF	1.98E-06	1.62E-01	1.67E-01			
θ	EKF	2.70E-07	1.02E-02	1.16E-02	2101.923	0	YES
	UIEKF	1.01E-07	1.97E-03	2.83E-03			
h	EKF	2.34E-07	3.06E-03	5.58E-03	15505.77	0	YES
	UIEKF	8.53E-08	1.42E-03	2.22E-03			

Table 2 listed the statistical value of all the estimated state between EKF and UIEKF. Overall, both values had significantly smaller average error, standard deviation, and root mean square error, but UIEKF outperformed EKF in all cases due to its lower value. On the other hand, based on ANOVA analysis, the consistency of low p-value ($p<0.05$) and high F value shown that UIEKF exceeds EKF in term of estimated state error.

4. Conclusion

The framework for implementing UIEKF for simulation has been established. The state estimator was simulated and its performance has been compared with the actual state and standard EKF. The result has shown that UIEKF was able to provide a more reliable and accurate estimation with the present of UI estimation compared to standard EKF. Multiple thrust profiles of sounding rocket were also integrated and estimated with exceptional results.

Acknowledgement

The author wishes to extend deepest gratitude to the advisor, Asst. Prof. Dr. Sarot SRANG for his guidance as well as Dynamics and Control Laboratory (DCLab) for financial support.

Reference

[1] D. Paikowsky, “What Is New Space? The Changing Ecosystem of Global Space Activity,” *New Space*, vol. 5, no. 2, pp. 84–88, Jun. 2017, doi: 10.1089/space.2016.0027.

[2] F. Motta, J. B. Pessoa Filho, and A. De Oliveira Moraes, “Is there a market for micro-launch vehicles?,” *Space Policy*, p. 101629, Apr. 2024, doi: 10.1016/j.spacepol.2024.101629.

[3] C.-S. Hsieh, “Extension of unbiased minimum-variance input and state estimation for systems with unknown inputs,” *Automatica*, vol. 45, no. 9, pp. 2149–2153, Sep. 2009, doi: 10.1016/j.automatica.2009.05.004.

[4] L. Meyer, D. Ichalal, and V. Vigneron, “An unknown input extended Kalman filter for nonlinear stochastic systems,” *Eur. J. Control*, vol. 56, pp. 51–61, Nov. 2020, doi: 10.1016/j.ejcon.2020.01.009.

[5] E. Ghahremani and I. Kamwa, “Dynamic State Estimation in Power System by Applying the Extended Kalman Filter With Unknown Inputs to Phasor Measurements,” *IEEE Trans. Power Syst.*, vol. 26, no. 4, pp. 2556–2566, Nov. 2011, doi: 10.1109/TPWRS.2011.2145396.

[6] Jann N. Yang, Silian Lin, Hongwei Huang, and Li Zhou, "An adaptive extended Kalman filter for structural damage identifications II: unknown inputs," *Struct. Control Health Monit.*, May 2006, doi: https://doi.org/10.1002/stc.171.

[7] W. Wei, H. Dourra, and G. G. Zhu, "Transfer Case Clutch Torque Estimation Using an Extended Kalman Filter With Unknown Input," *IEEEASME Trans. Mechatron.*, vol. 27, no. 5, pp. 2580–2588, Oct. 2022, doi: 10.1109/TMECH.2021.3117128.

[8] K. Ogata, *Modern control engineering*, 5th ed. Boston: Prentice-Hall, 2010.

[9] R. W. Beard and T. W. McLain, *Small unmanned aircraft: theory and practice*. Princeton, N.J: Princeton University Press, 2012.

[10] "Rocketry Software," Richard Nakka's Experimental Rocketry Web Site. Accessed: Apr. 15, 2024. [Online]. Available: https://www.nakka-rocketry.net/softw.html

Computational Model for Assessing Occlusal Force Analysis of Mandibular Central Incisor Restoration

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Abstract
This study investigates the feasibility for the new boundary conditions that are used to assess stress strain resulted from occlusal force from mandibular central incisor restoration. Digital Imaging and Communications in Medicine (DICOM) Data obtained from Cone Beam Computed Tomography (CBCT) scan of plastic skull were used to build up 3D model for Finite Element (FE) analysis. For implant and supra-structure, a restoration design was based on with the 3.3 diameter implant which was created using CAD (VISI, Hexagon AB, Sweden) based on measured dimensions from microscope. The restoration was placed in the bone position according to clinical practice. FE models were created based on CAD models. The element type here was a four-node tetrahedral element. The proposed method was to fix the mandibular condyle and a plane was positioned over the proximal end of the maxilla bone and assigned a position over time to simulate occlusal biomechanics which provides the resultant force of 60 N per tooth. From the analysis, the boundary condition generates the contact force of 59.9 N which was close enough to simulate the bite force. The EQV stress exhibited on implant and bone are reasonable.

Keywords: Occlusal Force, Mandibular Central Incisor Restoration, Computational

1. Introduction

This study will focus on feasibility for the new boundary conditions that are used to generate occlusal force from mandibular central incisor restoration. The study utilized screw-retained implants, commonly known as narrow-diameter implants. These implants are distinguished from standard implants by the reduced diameter of the fixture and offer potential advantages for individuals with limited bone structure or those who have experienced bone resorption [1]. The implant is crucial which required less bone volume for placement, resulting in reduced healing time due to the less invasive surgical procedure involved [2]. However, as the diameter of the latter is smaller, their mechanical strength is lower, and results in disadvantageous stress peaks affecting the crestal cortical bone [4] which may lead to additional marginal bone resorption [3]. To analysis the biomechanic resulted from occlusal force, it is commonly to apply direct load to the teeth. [5] However, this is no reflex the actual occlusal biomechanic. This study is therefore to find the potential new computational model for assessing this matter.

2. Materials and Methods

Digital Imaging and Communications in Medicine (DICOM) Data obtained from Cone Beam Computed Tomography (CBCT) scan of plastic skull were used to build up 3D model for Finite Element (FE) analysis. The DICOM dataset has a slice thickness of 0.25 mm, covering mandible and maxilla region. Using the open-source software 3D Slicer (slicer.org) [6], it was possible to obtain the 3D model from the DICOM data. The threshold function was utilized to distinguish

cortex from cancellous and separate the teeth from each other. Utilizing the tools integrated into the 3D Slicer, this separation can be achieved in the segment editor. Also, areas with different material properties can be isolated using threshold values.

Teeth included in analysis were central incisors, lateral incisors, and canines in maxilla and mandible. Bone included cortical and cancellous layer of maxilla and mandible. There was periodontal ligament surrounding the root of each tooth. The final models of bio-model were assembled in using CAD (VISI, Hexagon AB, Sweden) Regarding the incisal relationship, this study focused on occlusion of class 1. (Fig 1)

For implant and supra-structure, a restoration design was based on with the 3.3 diameter implant which was created using CAD (VISI, Hexagon AB, Sweden) based on measured dimensions from microscope. The restoration was placed in the bone position according to clinical practice.

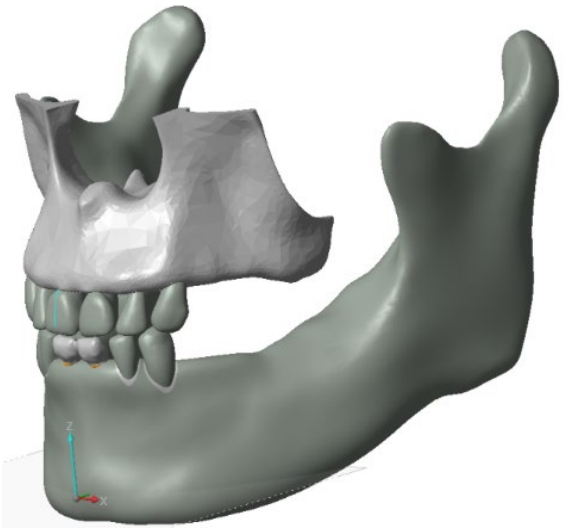

Fig.1 Final 3D Model.

FE models were created based on CAD model. The element type here was four-node tetrahedral element. Here, it provides the properties of each material assigned to the different regions. Elastic modulus (E) and Poisson's ratio (ν) of each material are as follows: maxilla and mandible cortical bone - E=14,700 MPa ν=0.30, maxilla and mandible cancellous - E=1,470 MPa ν=0.30, tooth - E=17,000 MPa ν=0.30, PDL=49 ν=0.34, implant – E=104,700 MPa ν=0.30, crown in zirconia E=200,000 ν=0.19, and abutment and retain screw – E =110,000 ν=0.19. [7-14]

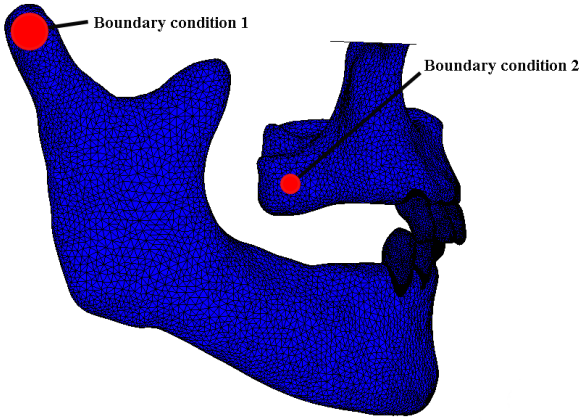

Fig.2 Boundary Conditions

Two types of relationships between the bodies are defined: Glue indicates a rigid bonding with no permitted relative movement whereas Touch represents a contact between elements with potential for relative movement. All bones-PDLs-natural teeth intact are glued. The contact between implants and bones are also glued. Specific friction coefficient is defined as 0.4 between the abutment and fixture while neglecting friction in other interfaces within the implant prosthesis. For teeth to crown and teeth to teeth, the friction is negligible.

In the FE model, mandibular condyles were fully fixed. To replicate occlusal forces, a plane was positioned over the proximal end of the maxilla bone and assigned a position over time to simulate occlusal biomechanics which provides the resultant force of 60 N per tooth.

3. Result

According to the FE analysis, the maxilla moved down and touched the teeth of mandible. It generates the contact force of 59.9 N which was close enough to simulate the bite force. Von Mises stress exhibited on abutment is 362 MPa, on retain screw is 392 MPa, and implant is 98 MPa. The elastic strain on marginal bone has seen its maximum values at 1060 micro stain.

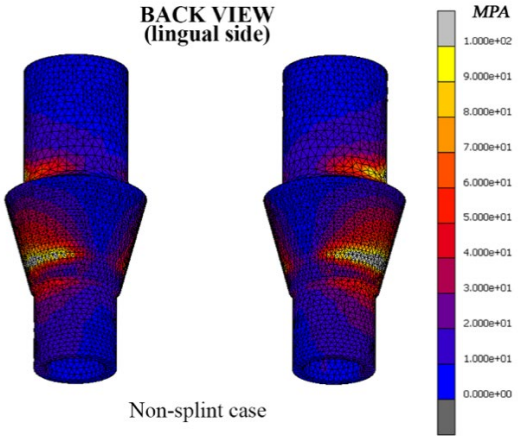

Fig.3 Stress distribution on abutment

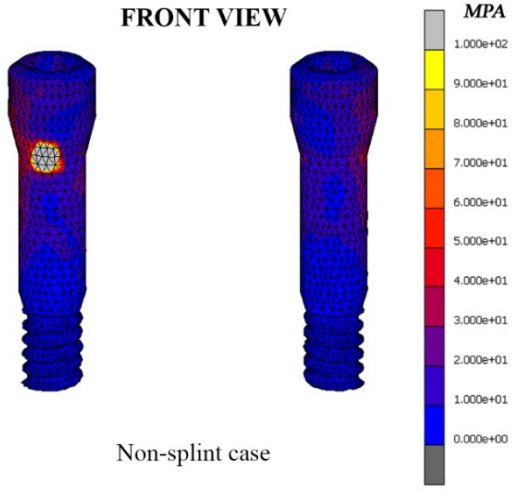

Fig.4 Stress distribution on retained screw.

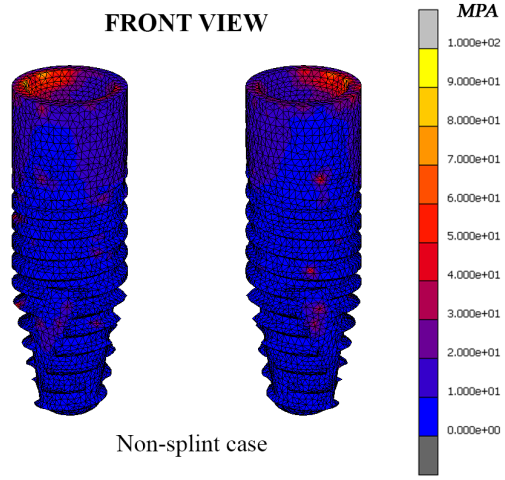

Fig.5 Stress distribution on retained screw.

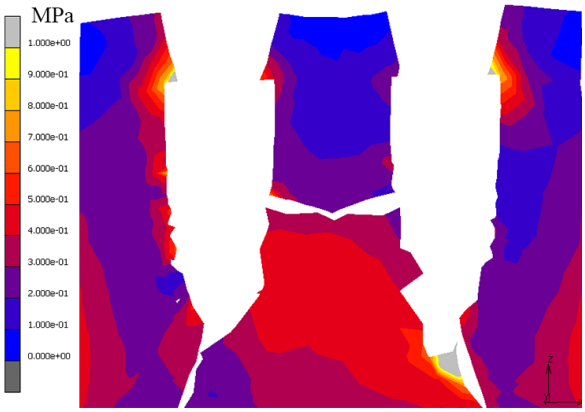

Fig. 6Mesiodistal cutting plane for non-splint case indicating elastic strain – Front view.

4. Conclusion

From a biomechanical standpoint, this study proposed a new simulation method with its boundary condition. With this boundary condition, it generated for occlusal force of 60N with reasonable stress magnitude.

Reference

[1] Klein M, Schiegnitz E, Al-Nawas B, Systematic Review on Success of Narrow-Diameter Dental Implants. The International Journal of Oral & Maxillofacial Implants, 2014. 43–54.

[2] Nisand D, Renouard F, Short implant in limited bone volume. Periodontology 2000, 2014. 66(1): p. 72-96. Maxillofacial Implants, 2014. 43–54.

[3] Onone Gialain I, Folmer Rodrigues da Silva L., Kasumi Gantier Takano M, Yagüe Ballester R, Guimarães Roscoe M, Barbosa Cruz Meira J, Peri-implant bone resorption risk of anterior maxilla narrow single implants: a finite-element analysis. Biomaterial Investigations in Dentistry, 2022. 9(1), 92–100.
[4] Agrawal S., Complication and Failure in Implantology. BFC Publications., 2022.
[5] Prasitwuttisak S, Chantarapanich N, Apinyauppatham K, Poomparnich K. Inglam S. Clinical challenges of biomechanical performance of narrow-diameter implants in maxillary posterior teeth in aging patients: A finite element analysis PLoS ONE, 2024. 19(3), 1–17, e0299816
[6] Fedorov A., B.R., Kalpathy-Cramer J., Finet J., Fillion-Robin J-C., Pujol S., Bauer C., Jennings D., Fennessy F.M., Sonka M., Buatti J., Aylward S.R., Miller J.V., Pieper S., Kikinis R., 3D Slicer as an Image Computing Platform for the Quantitative Imaging Network. Magnetic Resonance Imaging, 2012.
[7] Geng, J.P., K.B. Tan, and G.R. Liu, Application of finite element analysis in implant dentistry: a review of the literature. . J Prosthet Dent . 2001. 85(6): p. p. 585-98.
[8] Durmuş, G. and P. Oyar, Effects of post core materials on stress distribution in the restoration of mandibular second premolars: a finite element analysis. J Prosthet Dent, 2014. 112(3): p. 547-54.
[9] Weinstein, A.M., J.J. Klawitter, and S.D. Cook, Implant-bone interface characteristics of bioglass dental implants. J Biomed Mater Res, 1980. 14(1): p. p. 23-9.
[10]Brizuela-Velasco, A., et al, Mechanical Characterisation and Biomechanical and Biological Behaviours of Ti-Zr Binary-Alloy Dental Implants. Biomed Res Int, 2017: 2785863.
[11]Ha, S.-R., et al., Biomechanical three-dimensional finite element analysis of monolithic zirconia crown with different cement thickness. . Ceramics International, 2016. 42(13): p. p. 14928-14936.
[12]Poovarodom P, R.C., Suriyawanakul J, Li Q, Sasaki K, Yoda N, Rungsiyakull P., Effect of gingival height of a titanium base on the biomechanical behavior of 2-piece custom implant abutments: A 3-dimensional nonlinear finite element study. J Prosthet Dent, 2023.

Finite Element Analysis of the Impact of Incisal Relationship on the Biomechanical Performance of Narrow-Diameter Implants-Supported Restoration in Mandibular Anterior Teeth

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Abstract

This study investigated the biomechanical performance of narrow-diameter implant (NDI) treatment at single mandibular in anterior teeth in different incisal relationship by finite element analysis. The Maxillary arch and mandibular arch bone with upper and lower anterior teeth and single lower central incisor missing obtained from a patient's cone beam computed tomography data was simulated. Clinical simulations of three incisal relationship were conducted to simulating model. Three model groups were analyzed t 29N had NDIs of 2.9 × 10 mm in length with normal bite, 29D had NDIs of 2.9 × 10 mm in length with deep bite and 29E had NDIs of 2.9 × 10 mm in length with edge to edge. The applied load was 60 N. The results of the Von Mises stress on the implant fixture, the Von Mises stress on the abutment screw and the elastic strain of peri-implant bone were analyzed. Results showed that 29D model (deep bite) was the highest Von Mises stress of implant, Von Mises stress of abutment screw and elastic Strain in surrounding bone. Incisal relationship are influenced to biomechanical performance on NDI in single mandibular in anterior teeth. NDI category 1 can used single-tooth restoration in the mandibular anterior region. In addition, in the case of deep bite, the use of NDI category 1 in adequate bone must be careful to prevent biomechanical complication, which affects long term implant success.

Keywords: narrow-diameter implants, incisal relationship, dental implant biomechanics, finite element analysis

1. Introduction

The loss of anterior teeth has serious functional, esthetic disabilities, in addition to compromising the patients' quality of life. Clinical success of the use of implants in single or multiple restorations, including in the anterior region, is already established[1]. The success of the treatment depends on correct planning and bone availability so that the appropriate size of the implant is correctly indicated and installed, under adequate angulation[2]. Atrophy of the alveolar crest after extraction is a challenging limitation for dental implant placement[3]. In many cases, additional surgical procedures can be necessary to augment the insufficient bone. However, these augmentation procedures are time and cost-consuming and demand surgical expertise to minimize patients morbidity and prevent complications such as postoperative pain, infections, nerve damage, bone fractures, hemorrhage, wound dehiscences and implant or augmentation failures. Therefore, alternative concepts such as narrow-diameter implants (NDI) are becoming of increasing clinical and scientific interest. The definition of NDI is inconclusive in published studies, but in general a narrow-diameter implant is taken to have a diameter ≤3.5 mm. According to the classification of Klein et al., NDI are divided into the following three categories: Category 1 refers to implant has diameter <3.0 mm ("mini-

implants") suggest for non-load bearing area at anterior region, category 2 refers to 3.0–3.25 mm suggest for anterior region, mainly to replace at upper lateral incisor and lower incisor teeth and category 3 refers to 3.30–3.50 mm. can use in all region, including posterior single tooth restoration.

According to biomechanical aspect, load transferring to surrounding bone is a key factor for the long-term success of implant treatment. Thus, the important factors for a successful of a treatment are in addition to implant characteristics, such as implant diameter, quality of surrounding bone, including the direction of force that could affect the biomechanical behaviors of osseointegrated dental implants, especially in the anterior region[4, 5]. The relation of the upper and lower incisors when they are contact, the load direction is not in the long axis of an implant. [6]

According to the incisal relationship (ICR) [6] classified includes ***1) Ideal overjet and overbite or Class I, 2) Deep bite or Class II and 3) Edge-to-edge or class III***

However, The research of incisal relationship on biomechanical of NDI in mandibular implant is still limited. Thus, the purpose of this study is to evaluate the influence of implant diameter and incisal relationship on biomechanic behavior of single implant in mandibular anterior region through Finite Element Analysis (FEA).

2. Materials and Methods

Maxilla, mandible including anterior teeth were derived from CBCT radiographic imaging of patient with loss of mandibular anterior teeth and aged 50-80 years old in faculty of Dentistry, Thammasat University for reconstruction digital model for finite element analysis in this stydy. The study protocol was approved by the relevant Ethical Committee (Thammasat University (Medicine), Document Number 67DE066).

The finite element simulation involved six conditions

2.1 *Maxilla and mandible bone model*

CT images obtained from the canning process were performed segmentation to reconstruct the 3D model by the DentiiScann 2.0 (NECTEC,Thailand). To construct the final 3D model, anterior teeth (canine to canine), periodontal ligament (PDL) and bone were selected. a D2 bone type according to Misch classification[7] was designed containing 1.0 mm. cortical thickness bonded with the cancellous bone. D2 type of bone is most frequently found in the anterior mandible.

2.2 Implant model

A 3-dimensional (3D) bone level tapered implant system diameter 2.9 mm. and length 10 mm. ***(Institut Straumann AG, Basal, Switzerland) as shown in figure 2b used in this study was*** scanned by micro-computed tomography (micro-CT) and ***constructed*** from CAD software (Fusion 360, Autodesk, USA).

For mandibular incisor crown, create from exocad software program and exported as STL file format. The interface of the titanium abutment and zirconia crown was completely seated without any gap, and the cement layer was excluede

The implant model was fixed at the bone surface and juxtoposed with proximal of natural teeth. There are three incisal relationship classifications and three models as shown in Figure 1

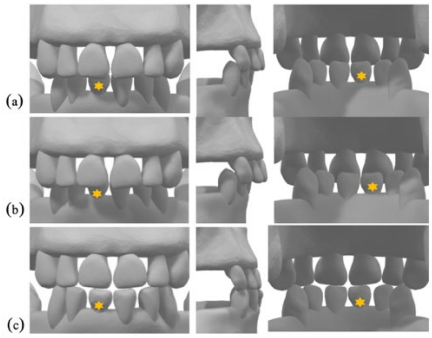

Figure 1 Three incisal relationship for each model in

the CAD software. **(**a**)** Class I,Normal bite [29N] ***(b)*** Class II ,Deep bite [29D] and **(**c**)** Class III ,Edge to edge [29E]
Note NDI in single lower mandibular teeth **(**yellow star**)**

The STL files were refined using reverse engineering software. The refined files were saved in STEP format. Subsequently, the image assembly was completed using CAD software, and saved as Parasolid files. The simulation was performed in finite element software MSC. Marc-Mentat (MSC Software Corp., USA). ***All interfaces in the models were assumed to be fully bonded*** [8]**.** Material mechanical properties of the model were assigned as shown in Table 1.

Table 1 The material properties in FEA model.[9-11]

Materials	Young's Modulus (MPa)	Poisson's Ratio	***Reference***
Cortical bone	13.7	0.30	***[12]***
Cancellous bone	7.9	0.30	***[12]***
Ti-15Zr	103.7	0.35	***[13]***
Titanium grade IV	110	0.30	[8]
Zirconia	205.0	0.19	[14]
Tooth	17	0.30	[15]
PDL	0.0689	0.45	[16]

2.3 Boundary condition

All models were meshed with four-node tetrahedral solid elements The total number of elements and nodes in the models were 862,607 and 219,337 respectively. The fixed support boundary conditions were assigned at condyle of mandible **(**1221 nodes**)** and loading application were indicated at plane of top maxilla in **(**2 nodes**)** as Figure 2a. According to the study of H Kumagai et al. [17], the force was applied in this study was 60 N [17] for conventional loading implant in mandibular anterior region.

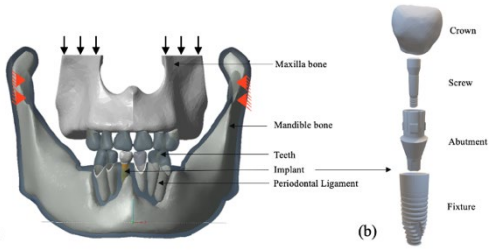

Figure 2 Three-dimensional virtual model features in the CAD software **(**a**)**The component of implant; fixture, abutment, abutment screw and crown **(**b**)**

3. Result

3.1 Equivalent Von Mises stress of implant

In clinical situation with different incisal relationship, the result shown that Von Mises stress of implant in deep bite **(**29D**)** was highest **(** 352.1 MPa**)** followed by normal occlusion **(**29N**) (**163.2 MPa **)** and edge to edge **(**29E**)(**121.4 MPa**)**. The maximun Von Mises stress of implant in all conditions were not greater than yield strength of ***Ti-15Zr*** (953 MPa**)** and titanium (680 MPa) [18]. The distribution pattern of the Von Mises stress of implant was similar for all conditions, which the stress concentrations were observed around the neck of implant at lingual side as shown on figure 3.

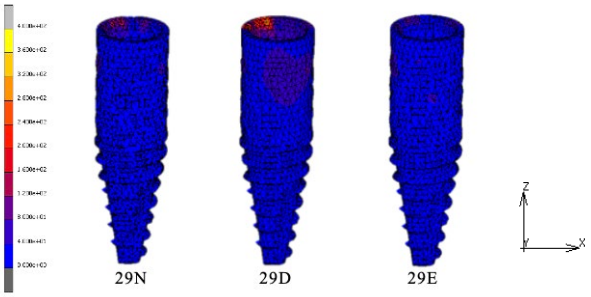

Figure 3 Distribution pattern of von Mises stress in implant

3.2 Equivalent Von Mises stress of abutment screw

In all situations, the neck of screw was under the highest stress as shown in figure 4. The 29D model had the highest Von Mises stress of screw at 89.06 MPa, followed by the 29E model at 62.53 MPa, and the model 29N at 48.31 MPa. Mises stress for the screw was on the distal side in both deep bites and normal bites. Whereas edge to edge occurs in the opposite direction.

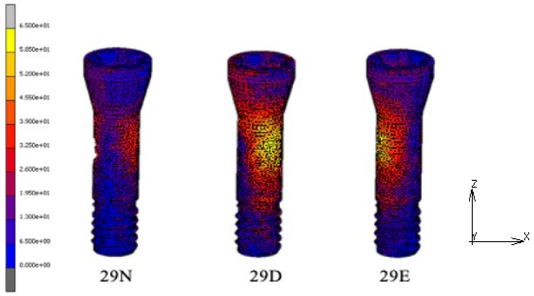

Figure 4 Distribution pattern of Von Mises stress in abutment screw

3.3 Equivalent Elastic Strain in surrounding bone

The highest of elastic strain value in cortical was 3,982 με in 29D model followed by 29N (3,647 με) and the lowest of elastic strain value observed in 29E model(2,808 με) . All clinical situations model showed comparable distribution patterns of strain in the bone around the implant, with the majority of the strains localized on the lingual side of the cortical bone in figure 5.

4. Conclusion

NDI diameter and Incisal relationship are influenced to biomechanical performance. NDI category 1 can used single- tooth restoration in the mandibular anterior region. A larger diameter result in better biomechanical stability. In addition, in the case of deep bite, the use of NDI category 1 in adequate bone must be careful to prevent biomechanical complication, which affects long term implant success.

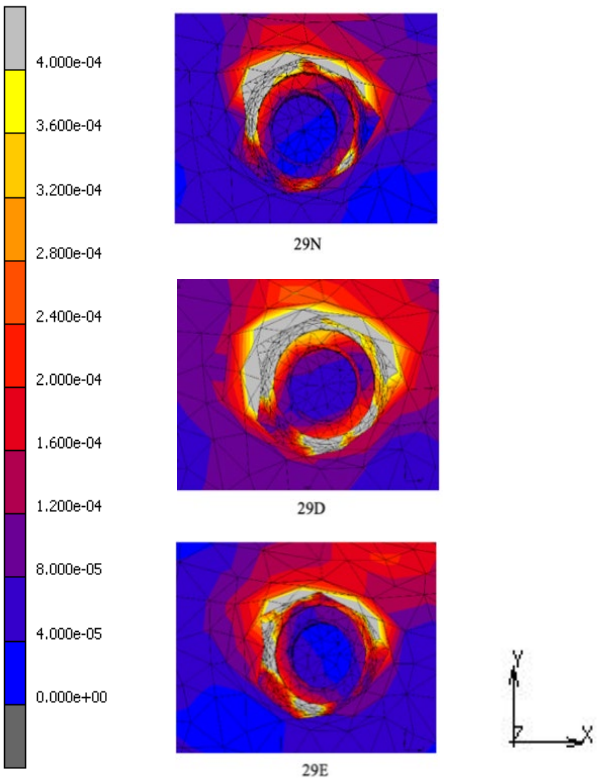

Figure 5 Maximum Equivalent Elastic Srain in bone

Acknowledgement

The authors would like to acknowledge the funding supported by the Department of Implantology, Faculty of Dentistry, Thammasat University and the software supported by Department of Mechanical Engineering, Faculty of Engineering at Sriracha, Kasetsart University.

Reference

[1] Haralur, S.B. and A.S. Al-Qahtani, Replacement of missing anterior teeth in a patient with chronic mouth breathing and tongue thrusting. Case Rep Dent, 2013. 2013: p. 759162.

[2] Kilic, E. and O. Doganay, Evaluation of Stress in Tilted Implant Concept With Variable Diameters in the Atrophic Mandible: Three-Dimensional Finite Element Analysis. Journal of Oral Implantology, 2020. 46(1): p. 19-26.

[3] Al-Nawas, B. and E. Schiegnitz, Augmentation procedures using bone substitute materials or autogenous bone - a systematic review and meta-analysis. Eur J Oral Implantol, 2014. 7 Suppl 2: p. S219-34.
[4] Chaichanasiri, E. and S. Inglam, The Combination Effects of Age-Related Bone Mechanical Property, Cortical Bone Thickness and Incisal Relationship on Biomechanical Performance of Narrow Diameter Implant Placed in Atrophic Anterior Maxilla: Finite Element Analysis. Engineering Journal, 2020. 24: p. 117-125.
[5] Schmitt de Andrade, G., et al., Biomechanics of implant-supported restorations. Brazilian Dental Science, 2023. 26: p. e3637.
[6] Morcos, S.S. and P.K. Patel, The vocabulary of dentofacial deformities. Clin Plast Surg, 2007. 34(3): p. 589-99.
[7] Misch, C.E. and K.W. Judy, Classification of partially edentulous arches for implant dentistry. Int J Oral Implantol, 1987. 4(2): p. 7-13.
[8] Poovarodom, P., et al., Effect of gingival height of a titanium base on the biomechanical behavior of 2-piece custom implant abutments: A 3-dimensional nonlinear finite element study. J Prosthet Dent, 2023. 130(3): p. 380.e1-380.e9.
[9] Jiang, Q., et al., Biomechanical Properties of First Maxillary Molars with Different Endodontic Cavities: A Finite Element Analysis. J Endod, 2018. 44(8): p. 1283-1288.
[10] Zhang, Y., et al., The Effect of Endodontic Access Cavities on Fracture Resistance of First Maxillary Molar Using the Extended Finite Element Method. J Endod, 2019. 45(3): p. 316-321.
[11] Zaytsev, D., Mechanical properties of human enamel under compression: On the feature of calculations. Mater Sci Eng C Mater Biol Appl, 2016. 62: p. 518-23.
[12] Geng, J.P., K.B. Tan, and G.R. Liu, Application of finite element analysis in implant dentistry: a review of the literature. J Prosthet Dent, 2001. 85(6): p. 585-98.
[13] Brizuela-Velasco, A., et al., Mechanical Characterisation and Biomechanical and Biological Behaviours of Ti-Zr Binary-Alloy Dental Implants. Biomed Res Int, 2017: p. 2785863.
[14] Ha, S.-R., et al., Biomechanical three-dimensional finite element analysis of monolithic zirconia crown with different cement thickness. Ceramics International, 2016. 42(13): p. 14928-14936.
[15] Santinoni, C., et al., Biomechanical analysis of narrow dental implants for maxillary anterior rehabilitation. Revista de Odontologia da UNESP, 2023. 52.
[16] Weinstein, A.M., J.J. Klawitter, and S.D. Cook, Implant-bone interface characteristics of bioglass dental implants. J Biomed Mater Res, 1980. 14(1): p. 23-9.
[17] Kumagai, H., et al., Occlusal force distribution on the dental arch during various levels of clenching. Journal of Oral Rehabilitation, 1999. 26(12): p. 932-935.
[18] Grandin, H., S. Berner, and M. Dard, A Review of Titanium Zirconium (TiZr) Alloys for Use in Endosseous Dental Implants. Materials, 2012. 5: p. 1348-1360.
[19] Shigemitsu, R., et al., Biological-data-based finite-element stress analysis of mandibular bone with implant-supported overdenture. Comput Biol Med, 2014. 54: p. 44-52.
[20] Schiegnitz, E. and B. Al-Nawas, Narrow-diameter implants: A systematic review and meta-analysis. Clin Oral Implants Res, 2018. 29 Suppl 16: p. 21-40.
[21] Wang, K., et al., Comparison of the fracture resistance of dental implants with different abutment taper angles.

Materials Science and Engineering: C, 2016. 63: p. 164-171.
[22] Flanagan, D., Management of a Fractured Implant Abutment Screw. Journal of Oral Implantology, 2016. 42(6): p. 508-511.
[23] Jemt, T., et al., Osseointegrated implants for single tooth replacement: a 1-year report from a multicenter prospective study. Int J Oral Maxillofac Implants, 1991. 6(1): p. 29-36.
[24] Naert, I., et al., A study of 589 consecutive implants supporting complete fixed prostheses. Part II: Prosthetic aspects. J Prosthet Dent, 1992. **68**(6): p. 949-56.
[25] Becker, W. and B.E. Becker, Replacement of maxillary and mandibular molars with single endosseous implant restorations: a retrospective study. J Prosthet Dent, 1995. **74**(1): p. 51-5.
[26] Frost, H.M., Bone's mechanostat: a 2003 update. Anat Rec A Discov Mol Cell Evol Biol, 2003. **275**(2): p. 1081-101.

Stress of PEEK Plastic Clamp on Access Prepared Tooth

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Abstract

This study used segmentation techniques to generate tooth models and analyze stress distribution of polyetheretherketone (PEEK) dental clamp in endodontically prepared tooth. A mandibular first molar with a traditional endodontic access cavity (TEC) was specifically developed for this investigation. The impact of the dental clamp on the tooth, focusing on its four-point contact at the cementoenamel junction (CEJ), was evaluated. The study revealed that the maximum von Mises (VM) stress value, reaching 1,358.52 MPa, was located on the enamel at the distolingual aspect. Additionally, within the dentin at the pulpal floor region, a greater distribution of force was observed on the distal side compared to the mesial side. Moreover, the maximum von Mises stress, measuring 5.84 MPa, was found on the distal aspect of the tooth.

Keywords: Polypropylene/Natural rubber, PEEK, Finite Element Analysis

1. Introduction

Root canal treatment is indicated when deep caries exposed pulp. The use of a rubber dam is essential in root canal treatments to prevent contamination from saliva and to protect soft tissues from irrigating solutions [1-3].

The rubber dam clamp is crucial for securing the rubber dam sheet in the correct position. Normally, rubber dam clamp is made of metal, but there have been developments in producing clamps from other materials such as polycarbonate or polyethylene terephthalate (PET). Currently, there are clamps made from polyetheretherketone (PEEK) available in the market, which are believed to exert less force on the teeth compared to metal and thus provide greater patient comfort during use[4,5].

Nevertheless, there has been no documented testing of the force exerted by PEEK clamps on tooth that have undergone access prepared for root canal treatment. This study aims to investigate the stress induced by PEEK clamp on endodontically access prepared mandibular first molar using finite element analysis.

2. Materials and methods

The study used a model of a caries-free mandibular first molar. The selected tooth must have no previous restoration and any defective on enamel, dentin along the crown and root area. This protocol underwent approval from the Human Research Ethics Committee of Thammasat University (Medicine), Document Number [67DE053].

2.1 Modeling the tooth and clamp

The mandibular first molar was scanned using micro-computed tomography (micro-CT) and reconstructed to create a

tooth model using segmentation approach technique. Endodontic access cavities were then designed on the solid model with CAD software. To create the model of the traditional endodontic cavity (TEC), defined as a straight-line access into the coronal third and middle third of the root canals, completed unroof the pulp chamber and tapering with convenient form. All canal orifices must be seen in direct bird eye view (Figure 1). CAD model of PEEK clamp was obtained from commercial designs available on the market (Figure 2).

Figure 1 TEC tooth model

Figure 2 Model of polyetheretherketone (PEEK) clamp

2.2 Finite element models

Finite Element (FE) models were created from 3D CAD models using automated mesh generation software (MSC Patran, MSC Software, US). Tetrahedral elements with four nodes were chosen for element generation. All FE analyses were conducted using commercial software (MSC Marc, MSC Software, US).

2.3 Material properties

All material properties assigned to the finite element models were assumed to be linearly elastic, homogeneous, and isotropic. The values corresponding to these material properties, as shown in Table 1.

Table 1 Mechanical Properties of Materials for FEA

Material	Elastic modulus (MPa)	Poisson's ratio
PEEK clamp	3,600	0.37
Enamel	84,100	0.33
Dentin	18,600	0.31
Pulp	2	0.45
Periodontal ligament	0.68	0.45
Gingiva	37	0.49
Cancellous bone	1,370	0.30
Cortical bone	13,700	0.30

2.4 Boundary conditions

The proximal end of cortical and cancellous bones in the FE models were fully constrained all degree of freedoms. The clamp was forced to expanded just over the height of contour and finally rested to the cementoenamel junction (CEJ).

2.5 Contact condition

For the tooth and periodontium, perfect bonding was assumed between each component. The beak of clamp must contact the tooth at four points around the CEJ. The interaction between the tooth and the clamp was modeled as frictionless contact.

3.Results

The maximum Von Mises (VM) stress was observed at the position where the beak of the clamp grips the tooth (Figure 3-6, Table 2 and 3). The maximum VM stress was 1,358.52 MPa at the distal side of lingual surface of the tooth (Distolingual line angle). It was noted that the VM stress in the enamel was higher than in the dentin at corresponding positions.

When examining the dentin in the pulpal floor region, the maximum VM stress was 5.84 MPa. Additionally, the stress on the pulpal floor was predominantly located on the distal side rather than the mesial side.

Table 2 The maximum Von Mises stress in enamel

VM stress (MPa)			
Outer			
MB	MLi	DB	DLi
61.64	86.45	149.97	1358.52
Abbreviation: MB=Mesiobuccal, ML=Mesiolingual, DB=Distobuccal, DL=Distolingual			

Table 3 The maximum Von Mises stress in dentin

VM stress (MPa)				
Outer				Pulp chamber
MB	MLi	DB	DLi	
28.64	21.86	63.65	104.55	5.84
Abbreviation: MB=Mesiobuccal, ML=Mesiolingual, DB=Distobuccal, DL=Distolingual				

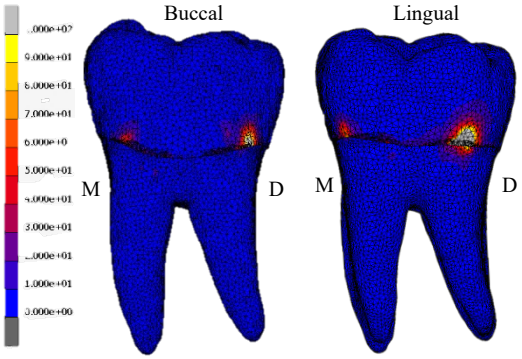

Figure 3 Von Mises stress on the tooth

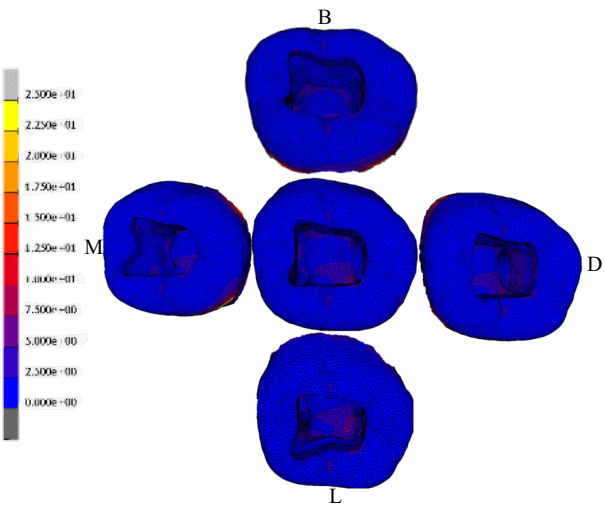

Figure 4 Von Mises stress at pulp chamber floor

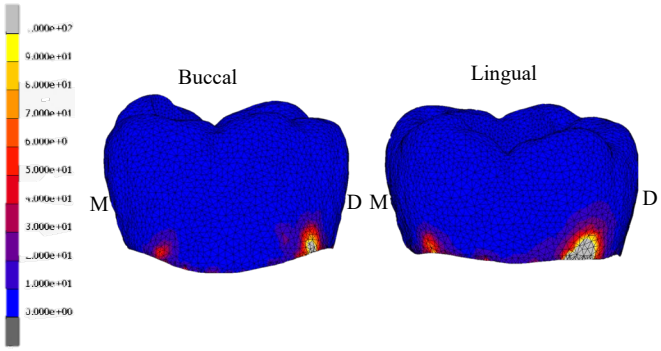

Figure 5 Von Mises stress at enamel

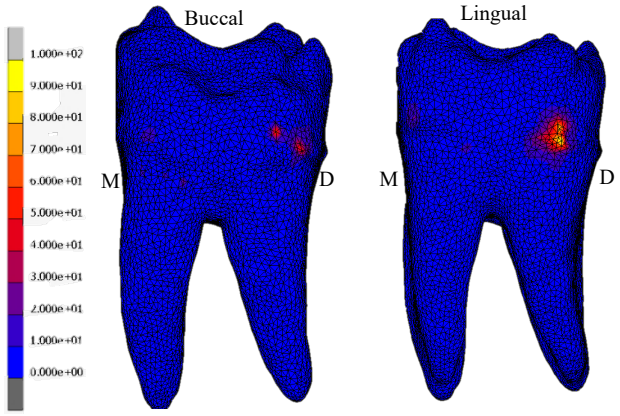

Figure 6 Von Mises stress at dentin

4. Discussion

This study used a segmentation technique to create models, in which accurately replicate tooth components in each segment, to closely resemble a real tooth for finite element analysis. The aim of this study was to investigate the stress induced by PEEK clamp on mandibular first molar with endodontic access cavity preparation.

The higher force on the distal side compared to the mesial side may be because it is closer to the source of the applied force, which is the bow of the clamp, allowing more force to pass through. Additionally, the wider beak on the distal side makes it greater contact with the tooth, resulting in increased stress and force on the tooth's distal side compared to the mesial side. The forces inside the pulp chamber or dentin corresponded to those exerted on the outer surface of the tooth. Specifically, more force was applied to the

distal side than the mesial side because the distal side received greater external force.

5. Conclusion

This study indicated that PEEK rubber dam clamp created stress at their contact points with the tooth. The distal side of the tooth had more stress applied from the clamp than the mesial side. This increased stress is observed both in the outer enamel and dentin within the pulp chamber. Therefore, when performing a root canal treatment, it is essential to assess the thickness of the remaining tooth structure especially on the distal side. If there is a limited remaining tooth structure, the stress from the clamp may weaken and cause the fracture of the tooth.

References

[1]. Ballal V, Khandelwal D, Saraswathi MV. Rubber dam in endodontics: An overview of recent advances. International Journal of Clinical Dentistry. 2013;6:319-30.
[2]. Ahmed HM, Cohen S, Lévy G, Steier L, Bukiet F. Rubber dam application in endodontic practice: an update on critical educational and ethical dilemmas. Australian dental journal. 2014;59(4):457-63.
[3]. Ahmad IA. Rubber dam usage for endodontic treatment: a review. International endodontic journal. 2009;42(11):963-72.
[4]. Mackenzie L, Waplington M, Bonsor S. Splendid Isolation: a Practical Guide to the Use of Rubber Dam Part 1. Dental Update. 2020;47:548-58.
[5]. Ferreira ECAF, Madalena IR, Küchler EC, Pereira TL, Honorato R, de Menezes FC, et al. Polyethylene terephthalate clamps: Optimization in endodontic and restorative practices. Journal of clinical and experimental dentistry. 2022;14(8):e621-e4.

Finite Element Analysis of Stress Distribution on Molar Tooth Impacted by Innovative Polypropylene/Natural Rubber Dam Clamp

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Abstract
This study investigated the stress distribution on molar tooth enamel and dentin using an innovative polypropylene/natural rubber (PP/NR) dam clamp through Finite Element Analysis (FEA). Three-dimensional models of the molar tooth, incorporating enamel and dentin layers, were developed. Clinical simulations of rubber dam clamp with four-point contact at the cervical region were conducted. Results showed that the PP/NR clamp had significantly less peak stress concentrations on the enamel and dentin. The PP/NR clamp indicates a more favorable option in terms of less stress concentration to enamel, and dentine.

Keywords: Polypropylene/Natural rubber, Finite Element Analysis

1. Introduction

Rubber dam application is an important isolation technique for successful dental restorative and endodontic treatments.[1, 2] It is recommended to use a rubber dam to isolate specific teeth and keep the work area free from contamination. This device helps by isolating the operative area, improving accessibility and visibility, protecting nearby soft tissues from accidental harm, and reducing the risk of patients swallowing or inhaling materials, fluids, or instruments.[2-5]

However, there are some drawbacks to the existing metal rubber dam clamps. These issues include potential stress to the enamel and dentin, the risk of the clamp slipping, difficulties in achieving a secure seal around teeth, and causing pain or discomfort for the patient[5-7] To reduce the risk of trauma to dental and gingival tissues and to increase patient comfort, a flexible (non-metallic) clamp could be a good solution[3, 6].

Our research team has focused on developing a new rubber dam clamp made from a combination of polypropylene (PP) and natural rubber (NR) in a 90:10 ratio. Previous pilot studies, and non-published data(8), have shown that this PP/NR proportion provides stable flexural strength, compressive strength, and hardness after 10 cycles of autoclaving. Therefore, this study was to investigate the stress distribution on molar tooth enamel and dentin using this innovative PP/NR dam clamp compared to a commercial soft polyether ether ketone (PEEK) and metal clamp through Finite Element Analysis (FEA).

2. Materials and Methods

The study used mandibular molar models without defects or restorations, approved by the Human Research Ethics Committee of Thammasat University (Medicine), COA No. 67DE053.

The finite element simulation evaluated dental clamp conditions PP/NR with four-point contact at the cervical region of the tooth, focusing on stress at the enamel and dentine.

2.1 Geometric construction of finite element model

2.1.1 The tooth

The model of a caries-free maxillary molar was created for finite element analysis using a high-resolution micro-CT scan (SkyScan 1275, Bruker-microCT, Kontich, Belgium), accurately capturing enamel, dentin, and other anatomical features. The tooth model was then reconstructed and created using CAD software (VISI, Vero Software, UK).

2.1.2 The clamp

For the PP/NR clamp, a 3D dental clamp design in STL file format was adjusted from the MOD clamp (The M Clamp - The World's First 3D Printable Rubber Dam Clamp, obtained from MOD Institute). The STL files were refined using Geomagic Studio 12 from Geomagic, Inc., Research Triangle Park, NC (now part of 3D Systems). The refined files were saved in STEP format. Subsequently, the image assembly was completed using CAD software, specifically VISI, Vero Software, UK, and saved as Parasolid files.

2.2 Development of Finite Element Model from Geometrical Model

Finite element (FE) models were developed from 3D CAD models utilizing automated mesh generation software (MSC Patran, MSC Software, USA). Tetrahedral elements with four nodes were selected for the mesh generation.

2.2.1 Material properties

In the finite element models, the material properties for all components, including enamel and dentin, were linearly elastic, homogeneous, and isotropic. These properties, as specified in Table 1, were consistently applied throughout the simulations. The properties of PP/NR were obtained from a previous unpublished study and are also included in Table 1.

Materials	Young's Modulus (MPa)	Poisson's Ratio
Enamel	84,100	0.33
Dentin	18,600	0.31
Periodontal ligament	0.68	0.45
Gingiva	50	0.3
Cancellous bone	1,370	0.30
Cortical bone	13,700	0.30
PP/NR	1,440	0.25

Table 1 The material properties in FEA model.[9-11]

2.2.2 Boundary and contact condition of 4-point contact of clamp to Molar model for Finite element analysis

In the finite element models, the proximal ends of the cortical and cancellous bones were fully constrained, restricting all degrees of freedom. The clamp was expanded to fit just above the concavity before settling at the cementoenamel junction (CEJ). To mimic clinical application, frictional contact points were identified on the maxillary molar at the mesiobuccal, mesiolingual, distobuccal, and distolingual sides. These contact points were constrained to prevent any movement, ensuring a stable attachment. The entire model, comprising the tooth, clamp, and

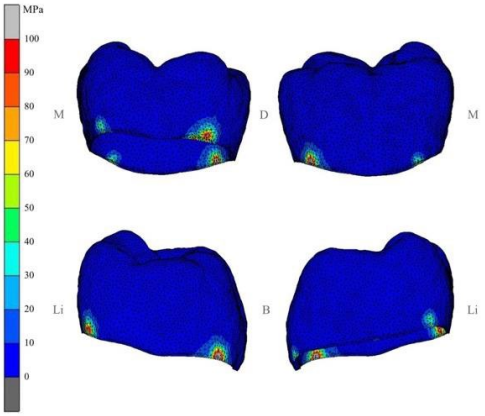

Figure 1 Von Mises stress distributions (MPa) in tooth enamel when using PP/NR Clamp. (D=Distal, M=Mesial, Li=Lingual, B=Buccal)

surrounding structures, was meshed, and analyzed using Marc Mentat (MSC Software Corp., USA), focusing on the von Mises stress distribution in the enamel, dentin, and clamp.

3. Results and Discussions

In enamel and dentin, the distribution of von Mises stress showed reduced concentrations when using the PP/NR dam clamp. The highest von Mises (VM) stresses were localized at the CEJ area of enamel and dentin, influenced by the four-point contact of the clamp with the tooth. Consistently higher stress concentrations were observed at the distal points of the tooth, including the distobuccal and distolingual regions. This correlates with the study of Eskibağlar *et al.*, 2023 on stress distribution on enamel and dentin caused by clamp application, which found that stainless steel clamps generated significantly higher stress (191.63 MPa) compared to PEEK commercial soft clamps (103.85 MPa), with the highest stress observed in the enamel tissue on the distal side.[3] Detailed stress distributions and values are presented in Figures 1, 2, and 3, as well as Table 2, with von Mises stress ranging between 7.72 and 145.98 MPa for enamel and dentin.

The VM stress from all clamps on the enamel is greater than the VM stress on dentin. This can described by involving the dentin-enamel junction (DEJ) can act as a stop or resist the transfer the force from the clamp as Finite element analysis conducted in the study reported that the DEJ in human teeth resists crack propagation by reducing stress at the crack tip.[12] Additionally, the enamel itself can absorb the force, thereby reducing the amount of stress that is transferred to the underlying dentin. [13]

VM stress of PP/NR clamp is typically higher at the distal contact points compared to mesial contact points. This is related to the distribution of stress within the tooth structure. The bow component of the clamp

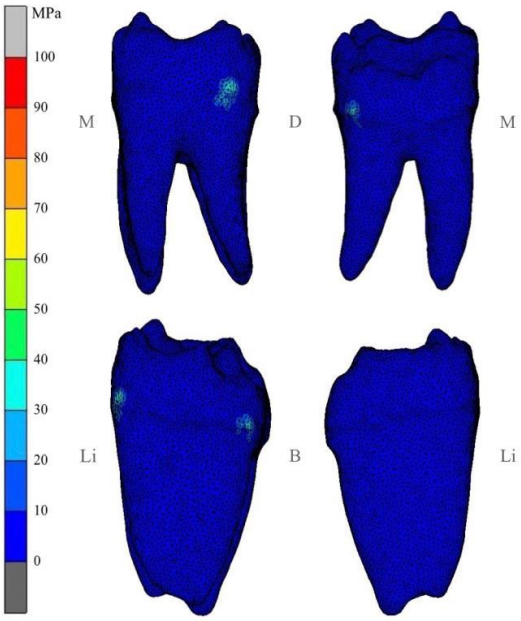

Figure 2 Von Mises stress distributions (MPa) in tooth dentine when using PP/NR Clamp (D=Distal, M=Mesial, Li=Lingual, B=Buccal)

can influence the stress transfer, with the distal contact point potentially bearing a large portion of the applied load. Moreover, after repeated use of rubber dam clamps undergo repeated stress when placed on a tooth during dental procedures, which may lead to clamp damage or cracks due to stress should be careful.

These findings conclude that the materials of dental clamp can have a significant impact on the stress distribution within enamel, and dentin of tooth structure, particularly at the distal contact point. The lower VM stress (on enamel and dentin and clamps) associated with the PP/NR clamp can

Clamp type	Enamel peak VM stress (MPa)				Dentin peak VM stress (MPa)			
	4 contact points				4 contact points			
	MB	MLi	DB	DLi	MB	MLi	DB	DLi
PP/NR clamp	23.31	58.52	100.60	219.20	11.01	6.10	27.12	51.09

Abbreviation: MB=Mesiobuccal, MLi=Mesiolingual, DB=Distobuccal, DLi=Distolingual

Table 2 The Von Mises stress distribution observed in enamel and dentine.

be attributed to their respective lowest hardness and compressive strength (non-

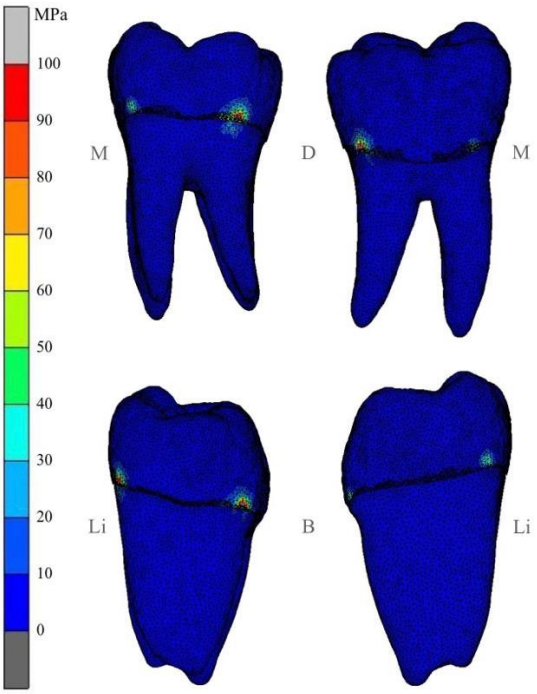

Figure 3 Von Mises stress distributions (MPa) in tooth enamel and dentine when using PP/NR Clamp (D=Distal, M=Mesial, Li=Lingual, B=Buccal)

published result of the pilot study)[8]. Softer material like PP/NR may be able to distribute the clamping force better, whereas stiffer materials like metal clamp may result in more stress concentration.

The limitation of this study is that it did not consider the clinical scenario where gingival recession is present. In such cases, the rubber dam clamp would attach to the tooth at a point below the cementoenamel junction (CEJ), rather than gripping the enamel directly.[7] When the clamp is positioned below the CEJ, it may not interact with the dentin in the same way as the scenarios examined in the study. The stress distribution and transfer to the dentin layer could potentially be different when the clamp is applied to the exposed root surface rather than the enamel. The stress distribution may also be different in the scenario where there are existing dental defects, such as caries, large restorations etc.

4. Conclusion

These findings highlight that while all clamps induce stress at their contact points with the tooth, the metal clamp shows a wider stress distribution pattern compared to the commercial PEEK soft clamp. Moreover, the PEEK clamp generally distributes stress more extensively than the PP/NR clamp. The PP/NR clamp indicates a more favorable option in terms of minimized stress concentration within the enamel, dentine, and clamp.

Acknowledgement

The authors would like to acknowledge the funding supported by the Department of Restorative and Esthetic Dentistry, Faculty of Dentistry, Thammasat University.

References

1. Falacho RI, Melo EA, Marques JA, Ramos JC, Guerra F, Blatz MB. Clinical in-situ evaluation of the effect of rubber dam isolation on bond strength to enamel. J Esthet Restor Dent. 2023;35(1):48-55.
2. Miao C, Yang X, Wong MC, Zou J, Zhou X, Li C, Wang Y. Rubber Dam Isolation for Restorative Treatment in Dental Patients. Cochrane Database Syst Rev. 2021;5(5):Cd009858.
3. Eskibağlar M, Erdem S, Kaman MO. Evaluation of the effect of different rubber dam clamps on the mandibular first molar with Finite element analysis. Comput Methods Biomech Biomed Engin. 2023;-:1-10.
4. Ahmad IA. Rubber dam usage for endodontic treatment: a review. Int Endod J. 2009;42(11):963-72.

5. Kantardzić I, Vasiljević D, Blazić L, Luzanin O. Influence of Cavity Design Preparation On Stress Values in Maxillary Premolar: A Finite Element Analysis. Croat Med J. 2012;53(6):568-76.
6. Doshi RJ, Shah NC, Mohan Kumar RS, Shah R, Kotecha N. Clinical evaluation of winged versus wingless rubber dam clamps in single tooth isolation - A randomized clinical study. J Conserv Dent. 2023;26(2):230-5.
7. Kaur A, Kumar V, Logani A. Accidental avulsion of a recently traumatised maxillary anterior tooth during rubber dam application. BMJ Case Rep. 2021;14(8).
8. Krajangta N, Nonthiphalang T, Phumpatrakom P, Rangsantham P, Wongwitthayakool P, Sirisinha C. Effect of repeated autoclave on hardness and tensile strength of polypropylene/natural rubber developed for rubber dam clamp 2024.
9. Jiang Q, Huang Y, Tu X, Li Z, He Y, Yang X. Biomechanical Properties of First Maxillary Molars with Different Endodontic Cavities: A Finite Element Analysis. J Endod. 2018;44(8):1283-8.
10. Zhang Y, Liu Y, She Y, Liang Y, Xu F, Fang C. The Effect of Endodontic Access Cavities on Fracture Resistance of First Maxillary Molar Using the Extended Finite Element Method. J Endod. 2019;45(3):316-21.
11. Zaytsev D. Mechanical properties of human enamel under compression: On the feature of calculations. Mater Sci Eng C Mater Biol Appl. 2016;62:518-23.
12. Jingjing Z, Tiezhou H, Hong T, Xueyan G, Cui W. [Mechanism of the dentino-enamel junction on the resist-crack propagation of human teeth by the finite element method]. Hua Xi Kou Qiang Yi Xue Za Zhi. 2014;32(5):464-6.
13. Marshall SJ, Balooch M, Habelitz S, Balooch G, Gallagher R, Marshall GW. The dentin–enamel junction—a natural, multilevel interface. Journal of the European Ceramic Society. 2003;23(15):2897-904.

Stress Distribution on the Root of the Upper Right Molar under Intrusive Force: A Finite Element Analysis

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Abstract

This study is designed to examine stress distribution of upper molar intrusion mechanic by the use of finite element analysis. The components of orthodontic intrusion mechanic are continuous archwire with orthodontic brackets on the teeth. Force application is assigned to apply at the bracket of the upper right first molar on buccal and palatal sides. Total magnitude of force is 200 grams and the direction of force is set to the apical direction to simulate intrusion force. The result of finite element analysis show stress concentration at mesiobuccal root of the upper right first molar. The observed maximum Von Mises stress is 0.04 MPa.

Keywords: Stress distribution, Molar intrusion, Finite element analysis

1. Introduction

Anterior open bite treatment is difficult because of its complicated etiology. The causes of anterior open bite may be skeletal factor, dental factor, respiratory factor, habitual factor or combined factors [1].

The conventional treatment techniques mainly based on intrusion of posterior teeth together with some extrusion of anterior teeth and also depend on patients' compliance. For severe anterior open bite patients, orthodontic treatment combined with orthognathic surgery may be indicated [2].

Posterior teeth intrusion can be done effectively with temporary anchorage devices. Using temporary anchorage devices is less invasiveness, less cost and less complication. Besides, temporary anchorage devices don't rely on patients' compliances [2].

However, associated mechanics and side effects of posterior teeth intrusion with temporary anchorage devices have not been clearly research. Besides, it has been known that risk of root resorption was associated with intrusive force but there is not enough research about correlation between magnitude of intrusive force and root resorption when posterior teeth were intruded [3].

The principle of finite element method is based on division of a complex structure into smaller sections called elements and its physical properties are input into the elements. Then, response to external stimulus, such as orthodontic force, can be calculated. Finite element method eliminates the necessity of experimental animal model in laboratory which is opposed to ethical issue. Instead, the studies of biomechanic responses to orthodontic forces can be done with finite element method [4].

2. Materials and methods

This research is experimental design, involved creating model of maxillary bone, PDL, upper teeth, orthodontic brackets, orthodontic wire, and from 3D image using CAD software. Then, finite element analysis of the model will be employed to create intrusive force on upper right first molar.

After that, the stress distribution will be investigated.

2.1 Modeling of the maxillary bone and teeth

3D image (DICOM file) of maxillary bone and maxillary teeth will be converted to 3D models via imaging. The 3D model of maxillary bone and maxillary teeth will be modified by engineering software. Then, CAD software will be used to create, arrange, modify and finalize the 3D model.

2.2 Modeling of the orthodontic bracket and wire

CAD software will be used to create the 3D model of orthodontic bracket, orthodontic wire.

2.3 Finite element analysis

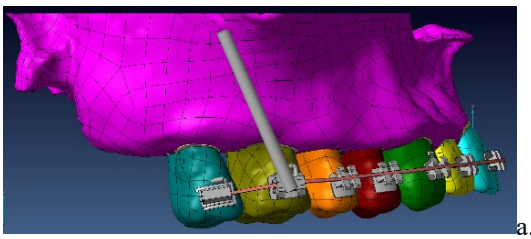
Deform3D will be employed for meshing and Marc Mentat (MSC Software Corp., USA) will be utilize for creating tetrahedral elements for the finite element mesh. Then, the analysis will be conduct. The properties of material will be used as specify in table below [5], [6].

Materials	Young's modulous (MPa)	Poisson's ratio
Cortical bone	13,700	0.26
Cancellous bone	1,370	0.3
PDL	0.6668	0.49
Teeth	19613.3	0.15
Stainless steel	200,000	0.3

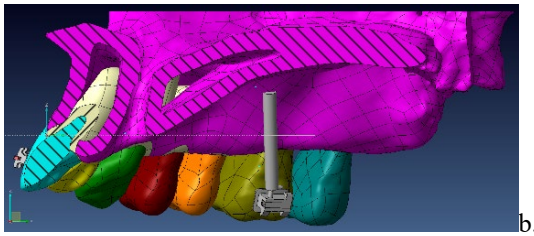
Table 1 Mechanical Properties of Materials

2.3 Force application

buccal bracket of upper right first molar, palatal bracket of upper right first molar. The intrusion force designed to apply in this study was 100 gram in total for each point (Figure 1).



a.

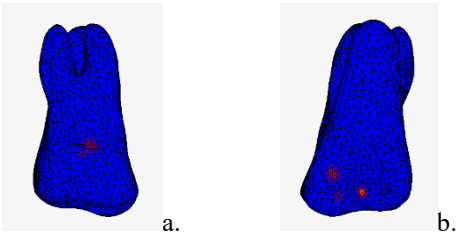


b.

Figure 1 point of force application and direction of force (a. show buccal view, b. show palatal view)

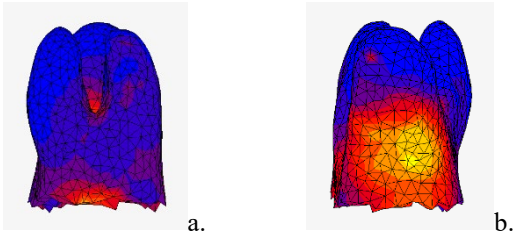
3. Results

The maximum Von Mises stress of the model was observed at orthodontic bracket which was the point of force application (Figure 2). Concentrated on the roots, the maximum Von Mises stress was observed at mesiobuccal root and equaled to 0.04 MPa (Figure 3).



a. b.

Figure 2 a. show buccal bracket, b. show palatal bracket



a. b.

Figure 3 stress distribution of the root

4. Discussion

The study's findings indicated that the highest levels of Von Mises stress occurred at the mesiobuccal root, and this stress concentration may be affected by the initial angle at which the tooth is positioned and the direction of the applied intrusive force. This suggests that both the starting orientation of the tooth and the vector of force used during intrusion play significant roles in determining the stress distribution within the root.

5. Conclusion

The maximum Von Mises stress was observed at mesiobuccal root of the upper right molar in response to intrusive force. The result suggested that mesiobuccal root may be at the greatest risk of root resorption under orthodontic posterior teeth intrusion mechanic.

References

[1] Gu D, Leroux B, Finkleman S, Todoki L, Greenlee G, Allareddy V, et al. Anterior openbite malocclusion in adults: Treatment stability and patient satisfaction in National Dental Practice-Based Research Network patients. The Angle Orthodontist. 2022;92(1):27-35.

[2] Reichert I, Figel P, Winchester L. Orthodontic treatment of anterior open bite: a review article—is surgery always necessary? Oral and maxillofacial surgery. 2014;18:271-7.

[3] Akl HE, El-Beialy AR, El-Ghafour MA, Abouelezz AM, El Sharaby FA. Root resorption associated with maxillary buccal segment intrusion using variable force magnitudes: A randomized clinical trial. The Angle Orthodontist. 2021;91(6):733-42.

[4] Knop L, Gandini Jr LG, Shintcovsk RL, Gandini MREAS. Scientific use of the finite element method in Orthodontics. Dental press journal of orthodontics. 2015;20:119-25.

[5] Tangsumroengvong V PV, Rungsiyakul C,Chalermwong H. Intrusion of Maxillary Posterior Teeth with Miniscrew Anchorage: A Finite Element Study. Khon Kaen Dent. 2021;24(1):91-101.

[6] Cifter M, Sarac M. Maxillary posterior intrusion mechanics with mini-implant anchorage evaluated with the finite element method. Am J Orthod Dentofacial Orthop. 2011;140(5): e233-41.

Utilization of Deep Learning for PR images segmentation in Detecting Potential Issues Related to Contact Between the Third Molar and the Mandibular Canal

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Abstract
This study focuses on detecting contact between the third molar and the mandibular canal through machine learning on radiographic panoramic (PR) images. These images were provided by Prof. Anan. Potential contact could signify neurological risks and difficulties in extraction of the third molar [1]. It is therefore crucial to detect the nature of the contact, if any. A two-month study was conducted to facilitate the dentists' work in reading these images. The use of YOLO (You Only Look Once) allowed the system to be trained and automatically detect the necessary entities for the study.

Keywords: Third molar, Mandibular canal, Deep learning, YOLO, Semantic Segmentation

1. Introduction

Reading panoramic images can sometimes be difficult and may require the use of CT scans, which are more expensive. An AI system could help avoid these additional costs by assisting dentists. This tool is therefore provided to them so that they can have different suggestions to make a choice more easily and effectively.

2. Materials and Methods

The study is based on a database of around a hundred confidential panoramic images provided beforehand. They were then segmented to extract only the necessary information using the online annotation tool CVAT AI. It is easy to use and allows generating segmentation masks that can be exploited for training the system. Thus, YOLO is a powerful tool for deep learning in speed and accuracy. It is also compatible with several platforms such as Google Colab, which allowed us to code the main part of the program. For this study, we used the latest version distributed by Ultralytics, YOLOv10.

2.1 Annotation for Panoramic Image Segmentation

The annotation method used is semantic segmentation, allowing each pixel of the image to be classified into one of three classes: background, third molar, or nerve (mandibular canal). The procedure involves annotating each image point by point, using CVAT AI, to form polygons belonging to one of the classes.

However, the number of images is not sufficient to have full confidence in it. This is the first approach to learn the functioning process of a deep learning method. Using CVAT AI, we generate a ZIP file containing the masks of the annotated images (black for background, red for third molar, and blue for nerve) (Figure 1).

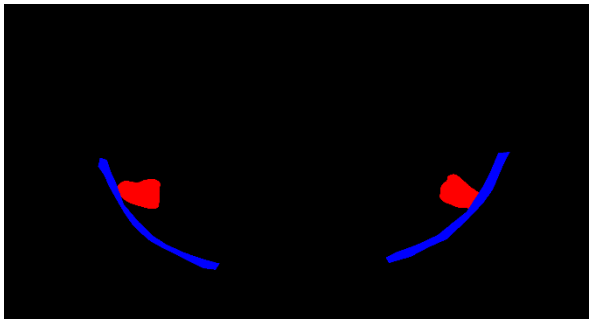

Figure 1 Mask generated by CVAT AI

2.2 Deep Learning Training of the System

Once the dataset is created and imported, we use Google Colab to write the code in Python. The data must be exploited using YOLOv10-seg, a pre-trained system for image segmentation. The method is to convert the masks (PNG files) into YOLO files (TXT files) [2] and then train our model to correctly recognize the classes. YOLO provides the model's performance during training, such as the confusion matrix and metrics.

2.3 Prediction Phase

We reuse the same images that were annotated but this time unmarked, to observe how the model detects and segments the image. We can then compare the results predicted by the model with the actual results (handmade annotations).

For now, training and prediction were done with few images. It is therefore important to emphasize that the metric evaluations are not representative [3-5]. These metrics were calculated using the *sklearn.metrics* library to obtain the F1 score, recall, precision and confusion matrix (Figure 2) (Table 1).

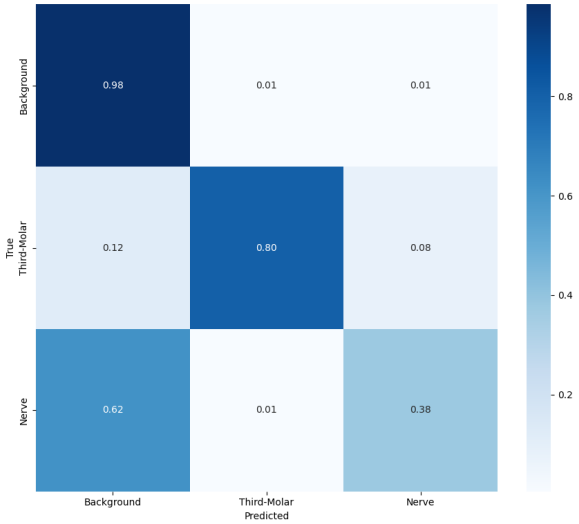

Figure 2 Confusion Matrix (Normalized)

2.4 Classification Phase

The predictions are then converted into masks (PNG files) to be processed and classified according to the type of contact: Contact, Suspected Contact, and No Contact.

3. Results and Discussions

The results are stored in a ZIP file where the details of the metric evaluations (Table 1) and predictions regarding the nature of the contact between the third molar and the mandibular canal can be found. We observe that the model's prediction is not precise visually (Figure 3 and 4), but it can still recognize the correct area.

Figure 3 Input PR image

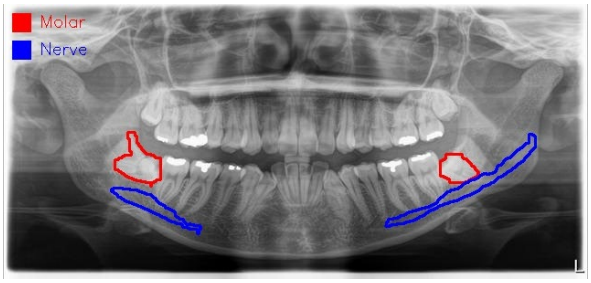

Figure 4 Output PR image with segmentations

Table 1 Evaluation Metrics

Class	F1 Score	Recall	Precision
Background	0.9843	0.9849	0.9836
Third Molar	3.0.5822	0.8034	0.4565
Nerve	0.4479	0.3787	0.5480

4. Conclusion

The use of CVAT AI and YOLO has facilitated the work as they are intuitive tools to use. The results remain consistent and, while waiting to exploit more data, they are still used to create and visualize a graphical interface. This interface takes an image uploaded by the user and returns the same image but segmented using the model.

Acknowledgement

The authors would like to acknowledge Professor Anan for providing PR images.

Reference

[1] Monaco G, Montevecchi M, Bonetti GA, Gatto MR, Checchi L. Reliability of panoramic radiography in evaluating the topographic relationship between the mandibular canal and impacted third molars. J Am Dent Assoc. 2004 Mar;135(3):312-8

[2] Computervisioneng. Image segmentation yolov8 – masks_to_polygons. Retrieved from https://github.com/computervisioneng/image-segmentation-yolov8/blob/main/masks_to_polygons.py

[3] Z. Mao, X. Huang, Y. Gong, H. Xiang and F. Zhang, "A Dataset and Ensemble Model for Glass Façade Segmentation in Oblique Aerial Images," in IEEE Geoscience and Remote Sensing Letters, vol. 19, pp. 1-5, 2022, Art no. 6513305

[4] T. J. Jang, K. C. Kim, H. C. Cho and J. K. Seo, "A Fully Automated Method for 3D Individual Tooth Identification and Segmentation in Dental CBCT," in IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 44, no. 10, pp. 6562-6568, 1 Oct. 2022

[5] L. Tang, L. C. Cai, K. Cheng, X. Wang, C. Luo and Y. Zhao, "Improved Yolov5n strip surface defect detection algorithm," 2023 CAA Symposium on Fault Detection, Supervision and Safety for Technical Processes (SAFEPROCESS), Yibin, China, 2023, pp. 1-5

Automatic Bone Segmentation from CT Scan Images for 3D Model Reconstruction

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Abstract
The reconstruction of 3D models plays a crucial role in facilitating the mechanical testing of medical devices. The manual process of 3D model reconstruction was time-consuming and labor-intensive. This research aims to create an automated program for segmentation of bone images from CT scan for further medical implementations. The objective is to reduce time and labor in preparation for a 3D model reconstruction. This research used MATLAB for bone segmentation from CT scan images and used 3D Slicer to reconstruct 3D models of the bones. The CT scan images are acquired under the consent of two master's degree students of Kasetsart University Sriracha. The CT scan image data set is stored in a DICOM file format and particular information is also specified with slice thickness of 0.5 to 1 mm. To demonstrate the performance of the automatic segmentation method, we have applied the algorithm to the CT images of the human lower body. The 3D model reconstruction from this research segmentation method has been improved to a 3D model with a smooth surface and without non-interested objects (noise). As a result, the elapsed time used for segmentation per image is around 0.75 to 0.85 seconds. Therefore, this research can help reduce the time and labor for making 3D models for those researching mechanical testing of medical devices. The research protocol can be applied to suit research involving the medical device design and applications which can be improved to suit another research.
Keywords: CT scan, 2D image segmentation, Lower extremity, 3D model reconstruction

1. Introduction

At present, medical science is advanced and widely developed. Then medical devices or equipment need to be developed according to accommodate the needs of doctors to treat patients [12,17,24]. Therefore, it is necessary to use the appropriate medical devices or equipment for that patient [19] which sometimes cannot be experimented with or tested with the real thing such as bone splint strength, testing bone screw test, etc. It is necessary to analyze medical devices or equipment to create a 3D model to study the strength or to investigate the safety of the medical device [15]. Therefore, obtaining 2D medical images, such as magnetic resonance imaging (MRI) or computed tomography (CT) images, are used to create a 3D model for experimentation [9,20]. The modeling process uses an engineering principle known as “reverse engineering” which a developing process that use a traceable analysis of existing prototypes by systematically studying and analyzing the prototype from materials, properties, and production processes [3,8,15,18,21]. Most research studies use experts in the system or application field to manually segment bone from soft tissue. The manual segmentation process is characterized by being time-consuming, labor- intensive, and cannot make the result of segmentation evenly. This is especially true when faced with many images that need additional expertise to handle large-scale segmentation tasks [1]. Figure 1 illustrates a manual segmentation process.

This research will be studied for the digitization phase for segmentation and the reconstruction phase to reduce the 3D reconstruction time because 3D

reconstruction takes a time-consuming process. Moreover, this study will focus on the use of CT Scan images to extract bone pixels from tissue pixels to reduce the expense of time for 2D segmentation.

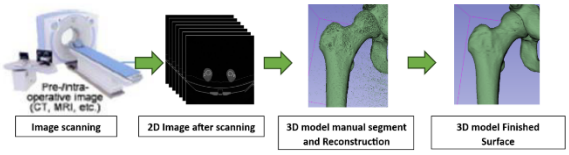


Figure 1 Manual segmentation process

2. Objective

This research aims to create an automated program for bone segmentation from CT scan images. Then the segmented images will be used to create 3D model for further medical applications. In addition, this should be utilized to aid analyzing the bone shape for plates design in biomedical engineering or the manufacture of medical devices.

So, the program should be able to separate pixels of bone region from various pixels of tissue regions automatically in a segmentation process. Furthermore, it should be able to stack each layer of bone region obtained from the segmentation process to create a bone 3D model with a medical image processing and visualization software. Finally, the program aims to reduce the amount of time that is normally spent in 3D reconstruction of bone 3D modelling.

3. Materials and methods

3.1 Data Collection

The CT scan images were acquired under the consent of two master's degree students of Kasetsart University Sriracha Campus via a CT scanner at Thammasat University Hospital for this research. The CT scan image data set is stored in a DICOM file format and particular information is also specified with slice thickness: 0.5 – 1 mm and number of slices: 3000 – 3300 per set.

3.2 Methodology

This research used MATLAB for bone segmentation from CT scan images, and 3D Slicer software to reconstruct bone 3D model. MATLAB has interactive image viewing and processing tools with special GUI developed to perform segmentation [2,31]. The developed tools have been designed to perform statistical analysis of the material in both 2D and 3D and have powerful graphic visualization capabilities [30]. The segmentation of CT scan images using some procedures that have been developed using a combination of morphological edge detection and skeletonization as shown in Figure 2.

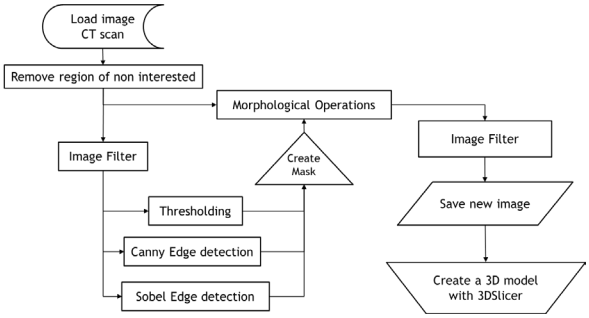


Figure 2 Proposed procedures of image segmentation and 3D model reconstruction in this study

3.3 Image Filter

Image filtering is a technique for editing or enhancing to highlight certain features in or remove noises from an image. Image processing that adopted filtering includes smoothing, sharpening, and edge enhancement. A neighborhood operation which is utilized for enhancing or extracting information from images by considering the relationships between pixels within a specified local region or neighborhood in filtering process. A pixel's neighborhood is some set of pixels determined by its position related to the considered pixel [25,27,29].

3.4 Thresholding

The thresholding is a technique to distinguish between the region of interest (ROI) and the background. The pixel's value is compared to a threshold target. If a pixel value is greater than the target threshold then the pixel value turns to 1 which is considered as an "object", and that pixel color is set to white. If a pixel value is less than or equal to the target threshold the pixel value will

become 0 which is considered a "background", and that pixel color is set to black. This process can be written as the following equation [11,26].

$$g(x,y) = \begin{cases} 1 & if\ f(x,y) > T \\ 0 & otherwise \end{cases} \quad (1)$$

; where T is the threshold value of interest, $g(x,y)$ is the pixel value after the threshold, $f(x,y)$ is the pixel value before thresholding, and (x,y) are the pixel coordinates.

3.5 Canny Edge detection

The Canny edge detection is one of most popular, powerful, and effective edge detection operators for edge segmentation algorithms, and the algorithm uses a multi-stage algorithm to detect a wide range of edges in an image. The aims of the algorithm are detection, localization, and finding out the number of responses. The principle of Canny operator is working on a multi-stage algorithm that performs smoothing by using Gaussian convolution and tracking process control by two thresholds. This operator provides good detection because it can show details contained in the image and can detect edges while removing noise in the image. The Canny method differs from the other edge-detection methods in which it uses two different thresholds to detect strong and weak edges. Moreover, the method includes the weak edges in the output only if they are connected to the strong edges [27,29].

3.6 Sobel Edge detection

The Sobel operator is widely used in the edge detection technique based on horizontal and vertical convolution of the image. This operator is sensitive to noise, but the advantage of this technique is that it produces better edge detection results with an easy implementation process. The Sobel edge detection or Sobel filter has the main algorithm to calculate the gradient of each pixel position inside the image. The Sobel operator calculates image gradients using simple integer-based kernels, which provide some inherent smoothing. As a result, it can have a modest noise reduction effect while primarily serving for edge detection [27,28,29].

3.7 Morphological Operations

The morphological operations in digital image processing refers to the mathematical morphology of a picture, which is a certain morphological processing of a picture using digital image processing algorithms. The morphological operations are part of the Morphological Operations in Image Processing Toolbox of MATLAB. These functions can be used to perform common image-processing tasks such as contrast enhancement, noise removal, thinning, skeletonization, filling, and segmentation [28,29,30].

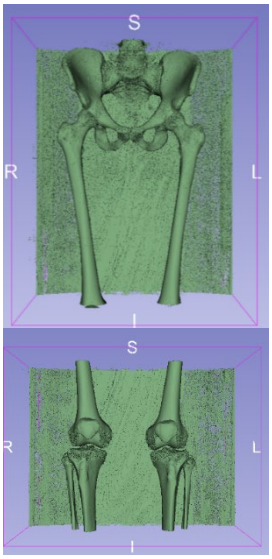
3.8 3D Image Reconstruction

Currently, there are many software in the market that can convert DICOM files to become a 3D model after superimposing. For this study, we used the 3DSlicer, a free open software to convert 2D image files to 3D model then export them as STL file [2,6,7,10,14,22].

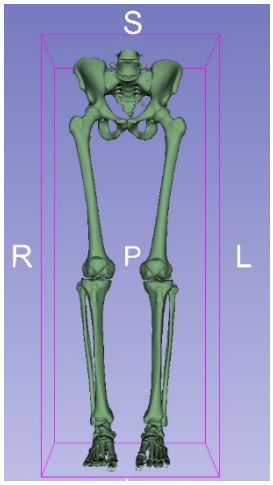
4. Results

To demonstrate the performance of the automatic segmentation method, we have applied the algorithm to the CT images of the lower extremity human's body in this research. The reconstruction of 3D models from original images and this research method are shown in Figure 3. Figure 3A is a direct reconstruction from the original images that still have some non-interested objects (noise) in the 3D model. Figure 3B is an improved reconstruction from this research's segmentation method that shows the 3D model with a smooth surface without noise.

Figure 4A, 4B, 4C, and 4D are compared results between a 3D model of direct reconstruction from original images (removal of the non-interested objects and others to compare only bone) and 3D model reconstructs from the proposed method applied to thigh and shin portions of two human bodies in this research.

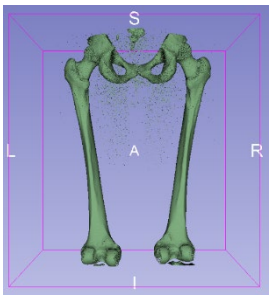


A. A 3D models directly reconstructed from original images

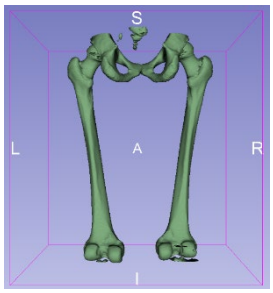


B. An improved 3D model reconstructed from the proposed method in this research

Figure 3 Results of 3D model reconstruct

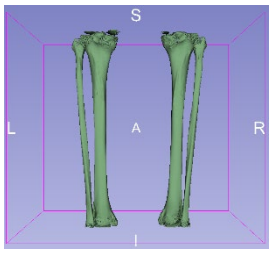


3D model directly reconstruct from original images

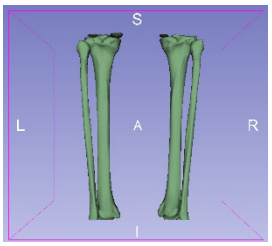


An improved 3D model reconstructed from the proposed method in this research

Figure 4A 3D models reconstruct of the thigh portion from the first human body

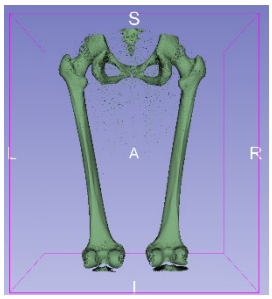


3D model directly reconstruct from original images

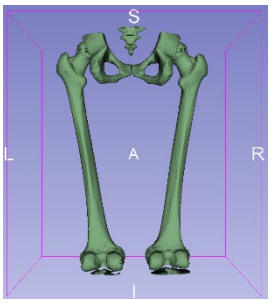


An improved 3D model reconstructed from the proposed method in this research

Figure 4B 3D models reconstruct of the shin portion from the first human body

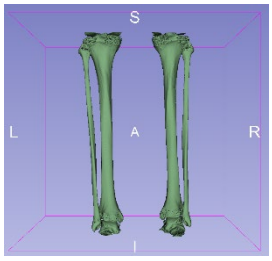


3D model directly reconstruct from original images

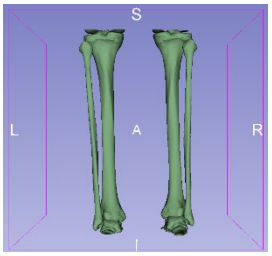


An improved 3D model reconstructed from the proposed method in this research

Figure 4C 3D models reconstruct of the thigh portion from the second human body



3D model directly reconstruct from original images



An improved 3D model reconstructed from the proposed method in this research

Figure 4D 3D models reconstruct of the shin portion from the second human body

The reduction of operating time for segmentation is one of the main objectives in this research. As a result, the elapsed time used for segmentation per image is around 0.75 to 0.85 second. The average results are shown in Table 1.

Table 1 Average time of bone segmentation implemented by the proposed method in this research

Sample	Number of images	Time for segmentation (Second)	Time for segmentation (Minute)	Avg. Time segmentation per image (Second)
First human body (thigh portion)	1332	1104	18	0.83
First human body (shin portion)	1092	924	15	0.85
Second human body (thigh portion)	1398	1170	20	0.84
Second human body (shin portion)	1176	890	15	0.76

5. Discussion

The 3D model is essential for medical studies to treat patients and necessary to analyse and synthesize for medical devices or equipment design. The ordinary reconstruction process of 3D Modeling takes a lot of time and effort of concise expertise to deal with. This research mainly focuses on bones of the lower extremity, especially femur and tibia. The results of comparison between 3D models from this research method and 3D models originated with the conventional reconstruction, these show significant improvement, especially at the epiphysis area of bone. Importantly, the average elapsed time for segmentation per image proposed by this research is around 0.75 to 0.85 second which means that segmentation time duration is just less than 1 hour for the case of 3600 images. However, it is hard to compare the result of time duration for reconstruction the 3D model between the method proposed in this research and the normal manual operation because almost of the previous researches did not mention the time consume for 3D models reconstruction.

6. Discussion

In this research, we have proposed a segmentation algorithm combining morphological operations and the edge detection algorithm to segment medical images automatically. The result shown that this algorithm can segment the bone from the soft tissue and reconstruct 3D models from these images with good appearance surfaces. Moreover, it also significantly reduces the time duration for segmentation. The further study should be an improvement of the procedure in this research to mitigate some drawbacks in segmentation at the epiphysis area of bone by adding new methods of the segment such as separating images before doing segmentation.

7 Reference

[1] Abu Nasser M. Accelerated Digitally Reconstructed Radiograph (DRR) Using Automatic Body Segmentation 2018.

[2] Bahkali I.M. and Semwal S.K. Multiple Ways for Medical Data Visualization Using 3D Slicer. 2020 International Conference on Computational Science and Computational Intelligence (CSCI); 2020 16-18 Dec. 2020.

[3] Chantarapanich N., Rojanasthien S., Chernchujit B., Mahaisavariya B., Karunratanakul K. and Chalermkarnnon P. 3D CAD/reverse engineering technique for assessment of Thai morphology: Proximal femur and acetabulum. J Orthop Sci. 2017;22(4):703-9.

[4] Chantarapanich N., Sitthiseripratip K., Mahaisavariya B. and Siribodhi P. Biomechanical performance of retrograde nail for supracondylar fractures stabilization. Medical & Biological Engineering & Computing. 2016;54(6):939-52.

[5] Chen P., Weng J. and Kuo J. Combined computer-aided and 3D printing technology for pre-operative planning in spine fracture surgery. 2018 IEEE International Conference on Applied

System Invention (ICASI); 2018 13-17 April 2018.
[6] Cui J., Chang J., Wang Y., Wang H. and Shen K. Brain CT image segmentation based on 3D slicer. Journal of Complexity in Health Sciences. 2020;3(1):34-42.
[7] Fang L., Wan Z., Zeng W. and Cao P. Research on Internationalization of 3D Slicer. 2013 International Conference on Computer Sciences and Applications; 2013 14-15 Dec. 2013.
[8] Galantucci L.M., Percoco G., Angelelli G., Lopez C., Introna F., Liuzzi C. and De Donno A. Reverse engineering techniques applied to a human skull, for CAD 3D reconstruction and physical replication by rapid prototyping. J Med Eng Technol. 2006;30(2):102-11.
[9] Hounsfield G.N. Computed medical imaging. Science. 1980;210(4465):22-8.
[10] Kikinis R. and Pieper S. 3D Slicer as a tool for interactive brain tumor segmentation. 2011 Annual International Conference of the IEEE Engineering in Medicine and Biology Society; 2011 30 Aug.-3 Sept. 2011.
[11] Lahari M.S., Vijay and Anburajan M. Finite element analysis of femur in the evaluation of Osteoporosis. 2011 3rd International Conference on Electronics Computer Technology2011. p. 415-9.
[12] Minns R.J., Bibb R., Banks R. and Sutton R.A. The use of a reconstructed three-dimensional solid model from CT to aid the surgical management of a total knee arthroplasty: a case study. Medical engineering & physics. 2003;25 6:523-6.
[13] Nourisa J. and Rouhi G. Biomechanical evaluation of intramedullary nail and bone plate for the fixation of distal metaphyseal fractures. J Mech Behav Biomed Mater. 2016;56:34-44.
[14] Pieper S., Halle M. and Kikinis R. 3D Slicer. 2004 2nd IEEE International Symposium on Biomedical Imaging: Nano to Macro (IEEE Cat No 04EX821); 2004 18-18 April 2004.
[15] Popov I. and Onuh S.O. Reverse engineering of pelvic bone for hip joint replacement. J Med Eng Technol. 2009;33(6):454-9.
[16] Rahim M.S.M., Norouzi A., Rehman A. and Saba T. 3D bones segmentation based on CT images visualization. Biomedical Research (India). 2017;28:3641-4.
[17] Rahman A., Selmi S., Papadopoulos C. and Papaioannou G. CT-scan based FEA for the assessment of the effect of bone density on femur's fracture. 2009 9th International Conference on Information Technology and Applications in Biomedicine; 2009 4-7 Nov. 2009.
[18] Rooppakhun S., Chantarapanich N. and Sitthiseripratip K. Advanced Medical Imaging and Reverse Engineering Technologies in Craniometric Study. Forensic Medicine - From Old Problems to New Challenges2011.
[19] Sengupta R. and Kathirvelu. 3D modeling and stress analysis of dentures with magnetic implants. 2016 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET); 2016 23-25 March 2016.
[20] Sinthanayothin C. and Tharanon W. 3D-3D Registration: Surface Rendering Plus Skull and Soft Tissue Registration. 2006 1ST IEEE Conference on Industrial Electronics and Applications; 2006 24-26 May 2006.
[21] Starly B., Fang Z., Sun W., Shokoufandeh A. and Regli W. Three-Dimensional Reconstruction for Medical-CAD Modeling. Computer-Aided Design and Applications. 2005;2(1-4):431-8.
[22] 1. Uday P.A., Digvijay N. and Jeeva J.B. Pre-operative brain tumor segmentation using SLICER-3D. 2014 International Conference on Green Computing Communication and Electrical Engineering (ICGCCEE); 2014 6-8 March 2014.

[23] YeeWa C., YingPio L., Wang X. and KuanPhang C. Development CT-based three-dimensional complex skull model for Finite element analysis. 2012 IEEE Conference on Sustainable Utilization and Development in Engineering and Technology (STUDENT); 2012 6-9 Oct. 2012.
[24] Zhao Y., Wei Y., Cui X., Qu L., Liu L. and Wang Y. 3D display technology in medical imaging field. 2013 IEEE International Conference on Medical Imaging Physics and Engineering; 2013 19-20 Oct. 2013.
[25] Bao M., Guo S., Wang Y. and Tang Q. Improved bwmorph Function in the MATLAB Image Processing Toolbox for Fast Computation of Repeated Morphological Dilations and Erosions. 2009 Second International Conference on Intelligent Computation Technology and Automation; 2009 10-11 Oct. 2009.
[26] Chang K.Y., Wu Y.H., Lin W.L., Chen S.J. and Chen L.S. Vessel segmentation based on bone-to-bone elimination in brain CT angiography. 2016 IEEE International Conference on Consumer Electronics-Taiwan (ICCE-TW); 2016 27-29 May 2016.
[27] Hussain A., Muad A.M., Ahmad I. and Azhari C.H. MATLAB based image analysis software for characterization of microstructure materials. ICONIP '02 Proceedings of the 9th International Conference on Neural Information Processing Computational Intelligence for the E-Age (IEEE Cat No02EX575); 2002 19-21 Dec. 2002.
[28] Kutty S.B., Saaidin S., Yunus P.N.A.M. and Hassan S.A. Evaluation of canny and sobel operator for logo edge detection. 2014 International Symposium on Technology Management and Emerging Technologies; 2014 27-29 May 2014.
[29] Punarselvam E. and Suresh P. Edge Detection of CT scan Spine disc image using Canny Edge Detection Algorithm based on Magnitude and Edge Length. 3rd International Conference on Trendz in Information Sciences & Computing (TISC2011); 2011 8-9 Dec. 2011.
[30] Razali M.R.M., Ahmad N.S., Hassan R., Zaki Z.M. and Ismail W. Sobel and Canny Edges Segmentations for the Dental Age Assessment. 2014 International Conference on Computer Assisted System in Health; 2014 19-21 Dec. 2014.
[31] Wu T., Wang L. and Zhu J. Image Edge Detection Based on Sobel with Morphology. 2021 IEEE 5th Information Technology, Networking, Electronic and Automation Control Conference (ITNEC); 2021 15-17 Oct. 2021.

Reconstructing a Tibial Nail Using Reverse Engineering Techniques

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Abstract

The utilization of reverse engineering techniques in the reconstruction of tibial nails using CAD software such as VISI, marks a notable progression in orthopaedic surgery, especially in the treatment and reinforcement of tibial fractures. This research delves into an innovative strategy that harnesses reverse engineering principles to develop and produce personalized tibial nails. Through the utilization of 3D scanning technologies and computational modelling, intricate anatomical specifics of each patient's tibial structure are captured. This information enables the customization of tibial nails to enhance both fit and performance, offering the potential to enhance clinical results and expedite recovery processes. The findings underscore the potential of these advanced techniques to enhance the personalization of orthopaedic implants and pave the way for more effective fracture management.

Keywords: Tibia Nail, Reverse Engineering, 3D model Reconstruction

1. Introduction

EXPERT Tibial Nail is intended for temporary fixation, correction and stabilization of bones in the tibia [1]. The Tibial Nail made of Titanium alloy TAN. There are two types of Tibial Nail, as illustrate in Figure 1, which are the cannulated nails (ranging from Ø8 mm to Ø13 mm), suitable for both reamed and unreamed techniques, allow for nail insertion over a guide wire and solid nails (ranging from Ø 8 mm to Ø 10 mm) which only suitable for unreamed technique [2].

Figure 1. Tibial Nails [3].

Reverse engineering involves examining the design and functionality of an existing product or system and then replicating it

digitally to produce a comparable or enhanced version of the original product or system [4]. Consequently, reverse engineering techniques can be utilized to reconstruct the EXPERT Tibial Nail for subsequent analysis, including Finite Element Analysis, to enhance performance of the product and clinical results.

2. Method

The process commences with scanning the EXPERT Tibial Nail to create an STL file, as indicated in Figure 2, which is then utilized to reconstruct the Tibial Nail into a 3D model through CAD software such as VISI.

Figure 2. An STL file of scanned Tibial Nail

Subsequently, utilize a sketch line tool in VISI to establish a line from the scanned Tibial Nail, enabling the creation of a piped surface to manufacture Ø11mm cannulated nails with 315mm in length. Then, adhering to the guidelines outlined in the Expert Tibial Nail surgical manual for making the holes of locking screws (Ø5.0mm) and the Nail groove.

3. Result

The Figure 3 below illustrates the reconstructed 3D Tibial Nail model generated through reverse engineering techniques utilizing CAD software (VISI).

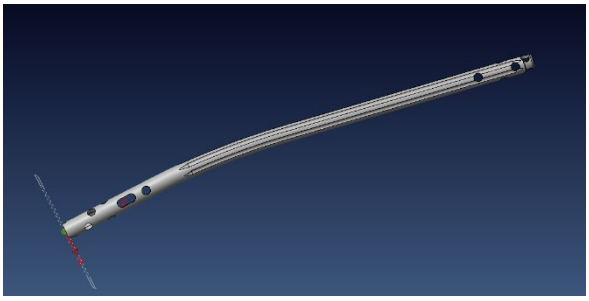

Figure 3. Reconstructed Tibial Nail

The utilization of reverse engineering techniques in reconstructing tibial nails through CAD software (VISI) has resulted in significant outcomes, including precision of fit, customization and design, manufacturing and validation, clinical evaluation, and comparative analysis.

4. Conclusion

These finding indicated that the use of reverse engineering methods in reconstructing tibial nails through CAD software such as VISI by Vero Software in the UK marks a significant change in orthopaedic implant design and tailoring. Through the application of advanced 3D scanning and computational modelling, this method enables the development of customized tibial nails that match the specific anatomical features of each patient. This enhances the precision of implant fitting, leading to improved surgical results and faster patient recovery. As technology progresses, the incorporation of reverse engineering methodologies into orthopaedic practice is anticipated to become increasingly common. This trend is expected to drive advancements in implant design and personalized treatments for patients.

Acknowledgement

The authors would like to acknowledge the software supported by Department od Mechanical Engineering, Faculty of Engineering at Sriracha, Kasetsart University.

Reference

[1] Johnson & Johnson MedTech. EXPERT™ Tibial Nail and EXPERT™ Tibial Nail PROtect™. DePuy Synthes. Retrieved from https://www.jnjmedtech.com/en-EMEA/product/expert-tibial-nail-etn#:~:text=Cannulated%20nails%20(from%20diameter%208,(no%20exchange%20tube%20required.

[2] DePuy Synthes Trauma, a division of Synthes GmbH. 2021. EXPERTTM TN Tibial Nail Surgical Technique. Retrieved from https://synthes.hs.llnwd.net/o16/LLNWMB8/INT%20Mobile/Synthes%20International/Product%20Support%20Material/legacy_Synthes_PDF/164459.pdf

[3] SYNTHES. Solid Tibial Nails (UTN) and Cannulated Tibial Nails (CTN). Mathys Medical. Retrieved from https://www.wpca.sydney/our-work/industry-skills-accelerator/learners/reverse-engineering-process/

[4] NSW Government. Reverse Engineering Process. Retrieved from https://www.rch.org.au/uploadedFiles/Main/Content/ortho/The_Titanium_Tibial_Nail_System.pdf

Automated Detection and Counting of Overlapping Steel Pipes Using Circular Hough Transform

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Abstract
This study presents an automated method for counting overlapping steel pipes using image processing techniques, specifically employing the Circular Hough Transform (CHT). The research addresses the limitations of manual counting methods, which are prone to human error and fatigue. A novel algorithm was developed to process images of two-layer pipe arrangements captured under controlled lighting conditions. The experimental setup included a webcam, 1000-watt light bulb, and a black partition to ensure consistent imaging. Steel pipes with specific dimensions were arranged in various configurations, and the images were processed using MATLAB. The algorithm effectively detected and counted pipes in both layers, accounting for overlaps. Results demonstrated complete accuracy in pipe detection, attributed to the consistent environmental conditions during image capture. This study highlights the importance of controlled imaging environments in achieving high accuracy in object detection tasks. The proposed method offers potential applications in industrial quality control and inventory management, providing a more efficient and accurate alternative to traditional counting methods.
Keywords: Steel pipe counting, Circular Hough Transform, Image processing, Automated inspection, Overlapping object detection

1. Introduction

Recently, automated systems for inspection tasks have been developed to replace human work. This is because human work is prone to fatigue, which leads to more errors, and human time is more valuable than automated systems. For example, a study comparing the performance of humans and robots in moving objects found that using robots was more responsive and saved valuable human time [2]. Another example is the detection and alerting of intruders in surveillance areas using drones [3]. The results showed that the use of automated systems had an average accuracy of over 90%, which is only 5% less than human detection and alerting. Additionally, counting the number of people passing through a gate using cameras [4] increases convenience and allows humans to spend time on other more efficient tasks.

Counting steel pipes using human labor is a task with a high workload and low efficiency. Therefore, using technology to assist in counting pipes will help improve the accuracy and efficiency of the count, while also reducing the workload on humans who are prone to fatigue and have lower accuracy. Automated counting using image processing methods has been found to produce more efficient and accurate counting results [5].

The Hough transform is a popular method used in computer image processing, such as detecting road lines from aerial photographs. The Hough transform can also detect various geometric shapes, including circles and ellipses. The equation for a straight line in the Cartesian coordinate system is [6]

$$y = mx + c \qquad (1)$$

; where m is the slope and c are the y-intercept, which cannot be used in the Hough transform method because when the line is perpendicular to the x-axis, it results in the slope (m) and the y-intercept (c) having infinite values. Therefore, this equation cannot be used. Instead, the equation for a straight line in the polar coordinate system must be used in the Hough transform method. The equation for a straight line in the polar coordinate system is

$$\rho = xcos(\theta) + ysin(\theta) \qquad (2)$$

; where θ is the angle of the line with respect to the x-axis, and ρ is the length of the line [6]. For circle detection, a modification of the Hough transform method is used, generally called the Circular Hough Transform (CHT). This method is widely used for circle detection because it can detect circles even when the input image has noise [7]. It also reduces computational complexity [8]. The equation that describes a circle is

$$r^2 = (x - a)^2 + (y - b)^2 \qquad (3)$$

; where r is the radius of the circle, and a and b are the coordinates of the center in the Cartesian x, y coordinate system. The first step in detecting circles using image processing is to find all the edges of the image using techniques like Canny, Sobel, or Morphological edge detection. Then, circles are drawn on the edges of the circle from the input image. The radius of the drawn circles depends on the specified radius values. The CHT method requires two radius values, and it will draw circles from the smallest radius to the largest radius. Then, it finds the intersection points of each circle's edge. The point with the most intersections will be the center of the circle in the input image [9].

The use of Hough transform is a popular method for object detection in image processing. For instance, the circle Hough transform is used for counting red blood cells by detecting the edges of red blood cells using the Canny method and counting the cells using the circle Hough transform [10]. It's also used for detecting circular objects on water surfaces with unmanned boats in real-time [11]. Additionally, a developed Hough transform method has been used to count steel pipes with accurate detection results [12]. From the literature review, there have been no studies on counting overlapping steel pipes in multiple layers, and no one has combined the circle counting method using Circle Hough transform with controlling the environmental conditions during image capture. Therefore, this research will focus on studying the methodology for counting two-layer overlapping pipes using image processing techniques.

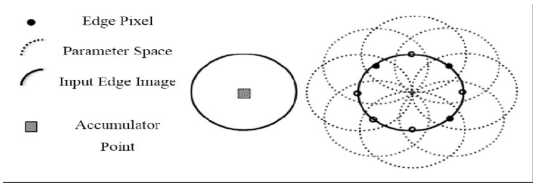

Figure 1 Image showing an example of circle drawing for circle detection [1]

This research will be beneficial for those who want to study image processing methods for object detection in photographs. It can also be improved or applied to counting methods for objects in similar tasks. The use of this methodology for counting multiple layers of overlapping pipes through image processing will help increase the accuracy efficiency in pipe counting, which is better than counting methods that use uncalibrated weighing scales or manual counting by workers. This is because cameras and operating systems have different fatigue characteristics compared to humans.

2. Methodology

For this experiment, we used steel pipes with an outer diameter of 47 mm, a thickness of 4.5 mm, and a length of 40 mm. The equipment included a Lenovo IdeaPad 3 14ITL05 81X70098TA (Platinum Gray) computer, an Oker HD 819 webcam, 30x30

aluminum profiles, a blue box for arranging pipes, a 1000-watt light bulb, and a black partition is used as a background.

The experimental setup involved assembling a structure to mount the camera for image capture, installing the 1000-watt light bulb for illumination, and setting up the black partition to prevent external light interference, ensuring consistent lighting conditions for the photographs.

The experimental procedure began by turning on the installed light within the black partition and connecting the webcam to the computer via USB. Steel pipes were arranged in the container box, which was then placed inside the black partition for photography. The captured image files were input into a MATLAB algorithm for processing. After each round of pipe counting, the results were recorded, and the pipes were rearranged for different configurations. This process was repeated 12 times to test various pipe arrangements.

Throughout the experiment, we used image processing techniques to count the number of overlapping pipes, aiming to improve accuracy compared to traditional weighing or manual counting methods. This research contributes to the field of object detection in image processing and can be applied or adapted to similar counting tasks in various industries.

2.1 Algorithm for Counting Two-Layer Overlapping Pipes

Algorithm 1 Image Processing for counting circle in images
Input:
Read image of tubes in the 1st layer
Read Image of tubes in the 2nd layer

Output:
countall: Total count of circles detected
Step 1: Crop both input images
image layer1 croped ← Crop image layer1 with coordinates [xmin,ymin,xmax, ymax]
image layer2 croped ← Crop image layer2 with coordinates [xmin,ymin,xmax, ymax]
Step 2: Process Layer 1
Extract Red, Blue, and Green channels from image layer1 croped
For i from y min to y max: y value of coner top left
For j from x min to x max: x value of coner top left
If Red image layer1(i, j) ≥ color values in the image need to be changed.
or Green image layer1(i, j) ≥ color values in the image need to be changed or
Blue image layer1(i, j) ≥ color values in the image need to be changed
Set Red image layer1(i, j) = color max value
Set Green image layer1(i, j) = color max value
Set Blue image layer1(i, j) = color max value
For i from y min to y max: y value of coner top right
For j from x min to x max: x value of coner top right
If Red image layer1(i, j) ≥ color values in the image need to be changed.
or Green image layer1(i, j) ≥ color values in the image need to be changed or
Blue image layer1(i, j) ≥ color values in the image need to be changed
Set Red image layer1(i, j) = color max value
Set Green image layer1(i, j) = color max value
Set Blue image layer1(i, j) = color max value
For i from y min to y max: y value of coner bottom right
For j from x max: x value of coner bottom right
If Red image layer1(i, j) ≥ color values in the image need to be changed.
or Green image layer1(i, j) ≥ color values in the image need to be changed or
Blue image layer1(i, j) ≥ color values in the image need to be changed
Set Red image layer1(i, j) = color max value
Set Green image layer1(i, j) = color max value
Set Blue image layer1(i, j) = color max value
Calculate X(i, j) for each pixel (i, j) based on channel differences
For each pixel (i, j):
If X(i, j) ≥ Appropriate contrast of red and blue
or Red image layer1(i, j) ≤ color values in the image need to be changed
or Blue image layer1(i, j) ≤ color values in the image need to be changed
or Green image layer1(i, j) ≤ color values in the image need to be changed
Set Red image layer1(i, j) = color min value
Set Blue image layer1(i, j) = color min value
Set Green image layer1(i, j) = color min value
Convert the processed image to grayscale (Gray image layer1 cropped)
Apply Canny edge detection with a threshold

of Appropriate value for edge detection (Edgeimage image layer1 cropped)

Find circles in the edge-detected image with radii between min value of suitable radius and max value of suitable radius using Hough transform (centers image layer1, radii image layer1)

Remove overlapping circles with small differences in center positions

Count the remaining circles and store the count in count1

Step 3: Process Layer 2 (Similar to Step 2 with modifications)

Extract Red, Blue, and Green channels from image layer2 croped

Apply processing similar to Step 2 for Layer 2

Find circles in the edge-detected image with radii between min value of suitable radius and max value of suitable radius using Hough transform (centers image layer2, radii image layer2)

Remove overlapping circles with small differences in center positions

Count the remaining circles and store the count in count2

count ← 0

Image Visualization:

Show cropped images of image layer1 and image layer2

Show thresholded images TH image layer1 croped and TH image layer2 croped

Show grayscale images Gray image layer1 cropped and Gray image layer2 cropped

Show edge-detected images Edgeimage image layer1 croped and

Edgeimage image layer2 croped

Visualize Circles in Layer 1:

Show Edgeimage image layer1 croped

Overlay circle centers in blue (centers image layer1)

Overlay circles in blue with radii (radii image layer1)

Visualize Circles in Layer 2:

Show Edgeimage image layer 2 croped

Overlay circle centers in red (centers image layer 2)

Overlay circles in red with radii (radii image layer 2)

Count Circles in Both Layers:

For each circle in Layer 1:

For each circle in Layer 2:

Calculate differences in x and y coordinates (diff x layer1 2, diff y layer1 2)

Calculate differences in radii (diff radii layer1 2)

If differences are within thresholds:

Overlay a white cross on the matched circles

Increment count

Countall = Length of radii image layer1 + Length of radii image layer2 - count 1 - count2 - count

Return countall

3. Results

The arrangement of pipes in the first layer, type 1, refers to the arrangement of pipes in 5 rows, with 6 pieces per row as shown in Figure 2.

In Figure 3, the blue dots represent the center points of the steel pipes in the first layer. The red dots represent the center points of the steel pipes in the second layer. The white center points are the center points of the steel pipes in the first layer where there is an arrangement of steel pipes in the second layer on top.

Figure 2 Arrangement of pipes in the first layer, type 1

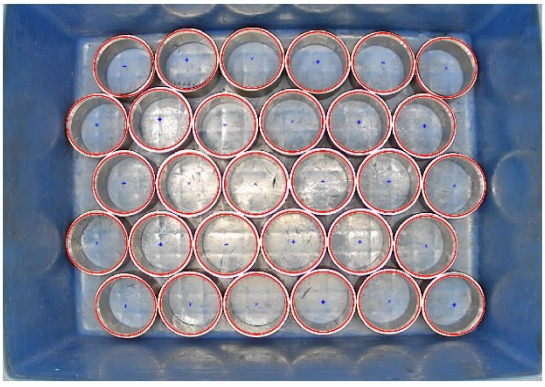

Figure 3 Detection results for the arrangement of pipes in the first layer, type 1

4. Discussion

The detection of steel pipes in the image was completely accurate. The key factor contributing to this accuracy was the consistent environmental conditions for all analyzed images. Each image was taken with a black partition and 1000-watt lighting, resulting in uniform edge detection and

accurate circle detection across all images. This contrasts with the results of Ghazali *et al*. [12], where inconsistent photography conditions led to counting errors.

5. Conclusion

The circle detection in the images was entirely accurate, with controlled and constant environmental conditions during photography. This highlights that changing external factors during image capture can reduce the accuracy of this detection method. This summary emphasizes the importance of controlled conditions in image processing for accurate object detection, particularly in counting overlapping pipes. It also acknowledges the contributions of both industry partners and academic advisors in completing the research.

Acknowledgement

The authors would like to thank Nippon Steel Pipe (Thailand) Co., Ltd. for providing the materials and equipment for this research. We also extend our gratitude to the advisory faculty in the Department of Mechanical Engineering and Design, Faculty of Engineering, Kasetsart University, Sriracha Campus, for their guidance, review, and corrections, which helped perfect this article.

Reference

[1] A. Anaz and D. Faris, "Comparison Between OpenCV and MATLAB Performance In Real Time Applications," vol. 23, 08/12 2015.

[2] T. Brito, J. Queiroz, L. Piardi, L. A. Fernandes, J. Lima, and P. Leitão, "A Machine Learning Approach for Collaborative Robot Smart Manufacturing Inspection for Quality Control Systems," Procedia Manufacturing, vol. 51, pp. 11-18, 2020/01/01/ 2020, doi: https://doi.org/10.1016/j.promfg.2020.10.003.

[3] F.-L. Chiper, A. Martian, C. Vladeanu, I. Marghescu, R. Craciunescu, and O. Fratu, "Drone Detection and Defense Systems: Survey and a Software-Defined Radio-Based Solution," vol. 22, no. 4, p. 1453, 2022. [Online]. Available: https://www.mdpi.com/1424-8220/22/4/1453.

[4] T. h. Chen, T. y. Chen, and Z. x. Chen, "An Intelligent People-Flow Counting Method for Passing Through a Gate," in 2006 IEEE Conference on Robotics, Automation and Mechatronics, 1-3 June 2006 2006, pp. 1-6, doi: 10.1109/RAMECH.2006.252623.

[5] Y.-S. Shin and J. Kim, "Automated Dimension Estimation of Steel Pipes Stacked at Construction Sites Using Euclidean Distances Calculated by Overlapping Segmentation," vol. 22, no. 12, p. 4517, 2022. [Online]. Available: https://www.mdpi.com/1424-8220/22/12/4517.

[6] R. C. Gonzalez and R. E. Woods, Digital image processing. Upper Saddle River, N.J.: Prentice Hall, 2008.

[7] C. Kimme, D. Ballard, and J. Sklansky, "Finding circles by an array of accumulators," vol. 18, no. 2 %J Commun. ACM, pp. 120–122, 1975, doi: 10.1145/360666.360677.

[8] D. Ioannou, W. Huda, and A. F. Laine, "Circle recognition through a 2D Hough Transform and radius histogramming," Image and Vision Computing, vol. 17, no. 1, pp. 15-26, 1999/01/01/ 1999, doi: https://doi.org/10.1016/S0262-8856(98)00090-0.

[9] M. Rizon et al., "Object Detection using Circular Hough Transform," American Journal of Applied Sciences, vol. 2, no. 12, 2005, doi: 10.3844/ajassp.2005.1606.1609.

[10] M. V. Caya, D. Padilla, G. Ombay, and A. J. Hernandez, "Detection and Counting of Red Blood Cells in Human Urine using Canny Edge Detection and Circle Hough Transform Algorithms," 29 Nov.-1 Dec. 2019 2019, pp. 1-5, doi: 10.1109/HNICEM48295.2019.9072708.

[11] N. F. S. Achmad Ghozy Tajuddin, Eko Budi Utomo, "Circle Hough Transform on Real-Time Object Following Unmanned Surface Vessel," International Electronics Symposium, 2019.

[12] M. F. Ghazali, L.-K. Wong, and J. See, "Automatic Detection and Counting of Circular and Rectangular Steel Bars," in 9th International Conference on Robotic, Vision, Signal Processing and Power Applications, Singapore, H. Ibrahim, S. Iqbal, S. S. Teoh, and M. T. Mustaffa, Eds., 2017// 2017: Springer Singapore, pp. 199-207.

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Sciences and Applied Sciences

Hydrosense: A hair-based Absorption system for heavy metal removal from wastewater

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Abstract
This study explores the utilization of human hair as a biosorbent for the removal of heavy metals from wastewater, addressing critical ecological and health risks. We developed a filtration device named "Hydrosense," which employs both untreated and chemically treated human hair to evaluate its adsorption capacities in simulated wastewater environments. The primary objectives were to determine the efficacy of human hair in removing heavy metals and to compare its performance with conventional industrial methods. Experimental results indicated that chemically treated hair significantly enhances the adsorption of heavy metals, achieving removal efficiencies comparable to existing treatments. This research underscores the potential of human hair as an efficient, cost-effective, and sustainable material for wastewater treatment applications.
Keywords : wastewater treatment, heavy metal removal, biosorbent, human hair, adsorption

1. Introduction

The global community contends with the profound repercussions of wastewater contamination. Heavy metal presence constitutes a significant hazard to ecosystems and the health of human populations [1]. These toxic substances infiltrate the body through diverse pathways, instigating a range of health complications. Acute exposure may induce symptoms such as headaches and nausea, whereas chronic accumulation heightens the risk of severe disorders like cerebral palsy and potentially results in mortality. Furthermore, wastewater pollution is linked to millions of annual deaths worldwide and adversely affects the health of approximately one billion individuals [2].

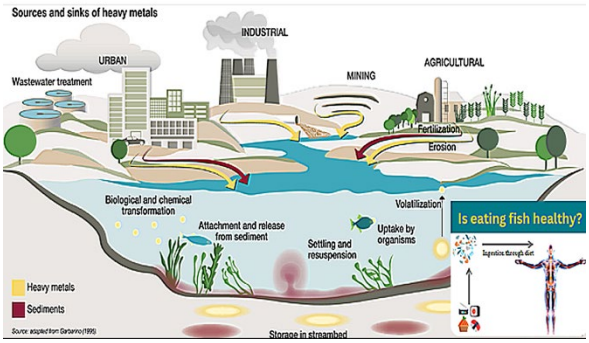


Figure 1. The sources of heavy metal pollution and the impact on the environment and humans

Inadequate wastewater treatment in Thailand systems from a vast number of factories operating outside regulated industrial zones. According to the Department of Industrial Works, 94% of the country's 77,400 factories[3-4] fall into this category, with 92% being small-scale facilities lacking centralized treatment systems. Prohibitive costs and limited effectiveness in heavy metal removal create major obstacles for smaller

businesses, leaving them ill-equipped to address this pollution concern. Compounding the problem is the lack of awareness and sustainable practices at the local level. In Bangkok, a researcher's observations highlighted the widespread issue of hair being discarded by barber shops, representing a missed opportunity for potential reuse or proper disposal.

Consequently, the investigation focused on identifying solutions addressing both heavy metal and hair discarding problem. The structural properties of hair revealed a potential for heavy metal sequestration from wastewater, specifically due to its constituent protein, keratin [5]. As a fibrous protein, keratin possesses an abundance of cysteine, an amino acid bearing a thiol (-SH) group. This thiol functionality acts as the primary binding site for heavy metals within the keratin structure. Additionally, amino (-NH2) and carboxyl (-COOH) groups contribute to metal adsorption, albeit to a lesser degree [6].

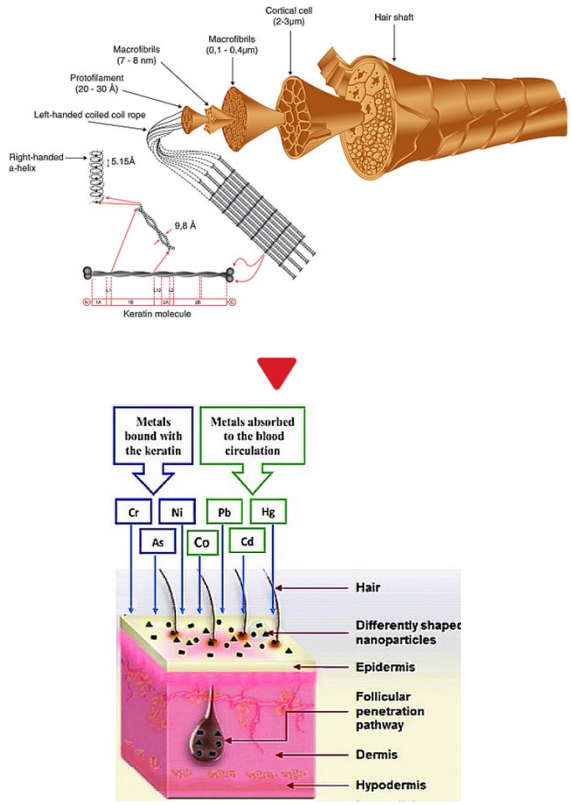


Figure 2. Mechanism of heavy metal absorption within hair structure [9]

Additional research explored the biosorptive capacity of both untreated and chemically treated human hair within a multi-metal system [7]. Experiments were conducted with a 0.1 mmol/L initial metal ion concentration, 24-hour contact time, pH of 4.0, and a 0.1 g biosorbent to 10 ml solution ratio. To enhance adsorption, a subset of hair samples was treated with hydrogen peroxide in an acidic medium, targeting the disulfide bonds in keratin. Results demonstrated significant uptake of cadmium (Cd), copper (Cu), and lead (Pb) – heavy metals frequently encountered in industrial wastewater [8]. Fourier-transform infrared spectroscopy (FT-IR) was employed to measure these capacities, substantiating keratin's potential as a heavy metal adsorbent. So, this information suggests that hair has the potential to capture heavy metals.

In our device, human hair was strategically selected as the filter material for intercepting heavy metals within wastewater. A specialized coating was applied to boost the device's adsorption capacity. The focus on user-friendliness is evident in the device's streamlined design for installation and upkeep. The integrated filter cartridge and cover system safeguards against hair loss while maximizing heavy metal removal. Findings substantiate the hair-based filter's efficiency, matching that of prevalent industry methods, and establish the framework for future expansion of this technology into the industrial sector.

2. Objective (Purpose)

1.To develop a heavy metal adsorbent in wastewater using hair:

While sedimentation tanks are common for heavy metal removal in wastewater, their cost and limited efficiency highlight a need for alternative solutions. Despite research demonstrating the potential of hair as a biosorbent [7], no devices

currently utilize this approach. This research proposes the development of a cost-effective, hair-based device tailored for integration into industrial wastewater systems.

2. To study the efficiency of heavy metal adsorption in wastewater using the device:

The device investigates the potential of treated hair, a readily available biomaterial, as a sustainable filtration medium for heavy metal adsorption in wastewater. The aim of this research is to determine the effectiveness of hair in binding specific heavy metals.

Hypothesis

Human hair can be developed into an effective heavy metal adsorbent for wastewater, and its absorption capacity can be further enhanced through specific chemical treatments or modifications.

3. Methods and Materials

3.1 Hair Treatment and SEM Characterization

3.1.1 Gathering and Preparing Hair Samples

Hair samples were gathered from local barbershops in Bangkok's Bang Khae District. These samples, which came from a variety of individuals, were then prepared for the experiment. This preparation involved washing the hair with a standard laboratory detergent, rinsing it multiple times with deionized water to remove any contaminants, and allowing it to dry at room temperature (22 ±1 °C). Once dried, the hair samples were cut into small pieces of about 1-2 mm in length using scissors.

3.1.2 Chemical Treatment of Hair Samples

A portion of the hair samples underwent a chemical treatment process to enhance their adsorption capacity for heavy metals. This process involved weighing 20.0 g of untreated hair and soaking it in 400 mL of a pretreatment reagent (10% H2O2) with an adjusted pH of 9. After a specific duration (5 hours), the solution was filtered to separate the hair. The hair samples were then washed multiple times with deionized water to remove any remaining reagents. To reduce the loss of treated hair during this process, the hair was separated from the washing water using centrifugation, and the liquid was then decanted. Finally, the treated and cleaned hair samples were allowed to dry at room temperature.

3.1.3 Preparation of a Heavy Metal Solution

A multi-metal solution was prepared for the adsorption experiment. This solution contained several heavy metal ions, such as Cr (III), Mn (II), Ni (II), Co (II), Cu (II), Zn (II), Cd (II), and Pb (II). These ions were created by dissolving the nitric salts of each metal in deionized water. A 1000 ppm stock solution was first prepared and diluted to achieve the desired initial heavy metal concentration for each experiment. The pH of the solution was adjusted as needed by adding sodium hydroxide and nitric acid.

3.1.4 Adsorption Experiment

The adsorption experiment was conducted by adding 0.1 g of biosorbent (either untreated or chemically treated hair) to 10 ml of the heavy metal solution. The mixture was gently stirred and left in contact for 24 hours at a pH of 4.0. This provided enough time for the heavy metals to bind to the hair samples.

3.1.5 SEM Analysis of Hair Samples

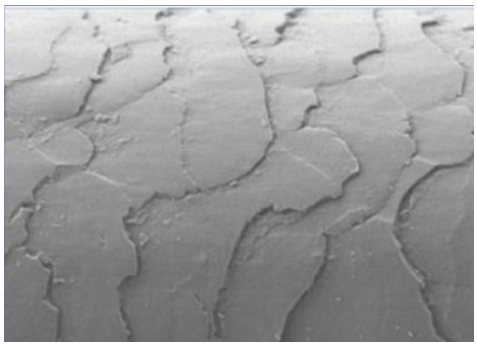


Figure 3. High-resolution SEM micrograph of hair surface (10 µm magnification) [7]

Scanning electron microscopy (SEM) was used to examine the morphological changes in hair samples before and after adsorption. This involved preparing the hair samples for SEM analysis, which may have included drying and mounting them on an appropriate holder. The SEM images provided valuable information about the surface characteristics of the hair samples and how they changed as a result of heavy metal adsorption. Comparing SEM images of untreated and treated hair samples helped visually confirm the adsorption of heavy metals on the hair.

3.2 Device Development and Design

3.2.1 Components and Specifications

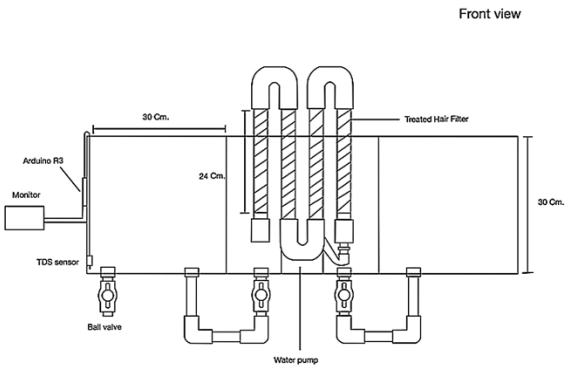
The Arduino Uno R3 (microcontroller) : functions as the central controller in this system, interfacing with the TDS sensor and transmitting data to a computer for monitoring purposes which show the quality water.

Figure 4. Arduino Uno R3 [10]

A TDS sensor (Total Dissolved Solids sensor): measures the concentration of dissolved solids in water, expressed in parts per million (ppm). Since heavy metals contribute to the total dissolved solids in water, a TDS sensor can provide an indirect indication of potential heavy metal contamination.

Figure 5. Analog TDS sensor module water solubility conductivity SEN0244

3.2.2. Device Structure and Material



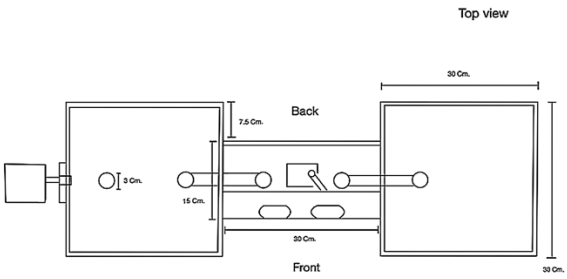
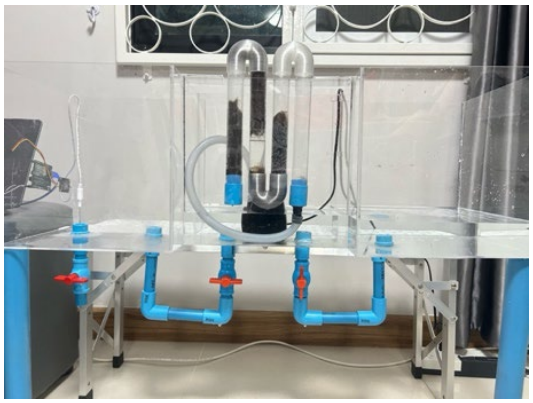


Figure 6. The device drawing in front view and top view

The device utilizes a tripartite acrylic chamber system for heavy metal filtration simulation. Wastewater contaminated with heavy metals is held in the initial compartment (30x30x30 cm). The central chamber (30x15x30 cm) functions as the filtration unit, containing an acrylic tube packed with 120 grams of treated hair. This tube interfaces with a U-shaped PETG pipe. A modified cap, containing cotton wool, prevents treated hair from exiting the filter and provides an inlet port for a water pump. Filtered water accumulates in the final compartment (30x30x30 cm). This final compartment is equipped with a ball valve for controlled release and a TDS sensor for quantifying the efficacy of heavy metal removal. This could illustrate the filtration of waste water system in factory.



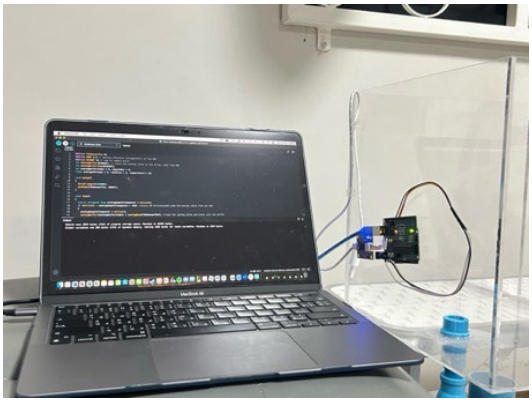


Figure 7. The picture of chamber part and monitoring part

Figure 8. Overview picture of the device

3.3 Device Operating System

3.3.1 Wastewater treatment system

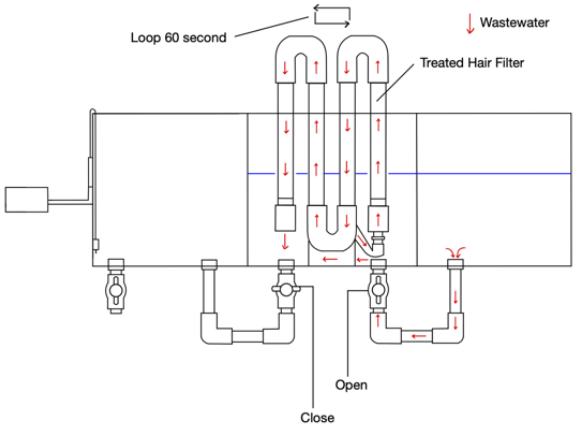


Figure 9. Diagram illustrating wastewater filtration cycle in the treated hair device.

The process initiates with the introduction of heavy metal-contaminated wastewater into the rightmost chamber.

Opening the first ball valve allows wastewater to flow via underlying piping into the central filtration chamber. The water pump then circulates the wastewater through the treated hair filter tubes. Filtered effluent exits via the final tube. Once water levels equalize between the two chambers, the system maintains this cycle for 60 seconds to optimize heavy metal capture by the hair filter (all of this process will open only the first ball valve on the right).

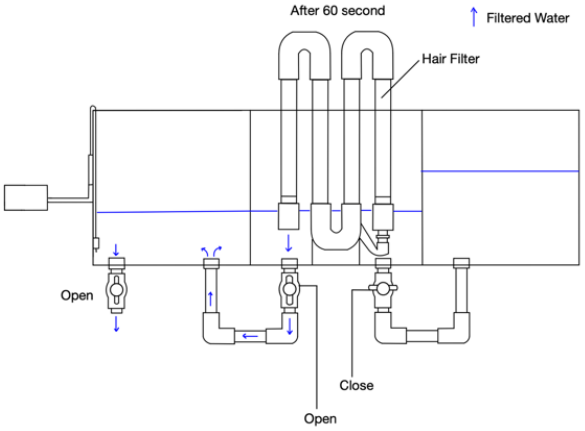


Figure 10. Diagram illustrating the filtered water quality assessment and release process.

After the 60-second filtration cycle, the first ball valve is closed, and the second ball valve is opened. This redirects filtered water to the final chamber. In this chamber, a TDS sensor monitors the remaining heavy metal concentration (in ppm) prior to release. The final ball valve controls the release of treated water from the system .

4. Results

4.1 Adsorption Capacity

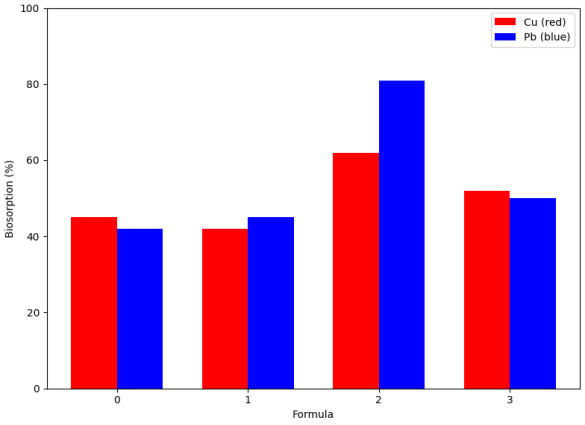
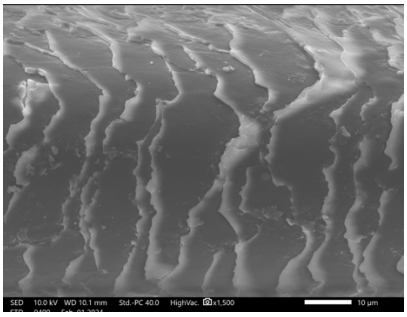


Figure 11. Compares hair absorption between treated hair (various formulas) and untreated hair (formula 0). Experimental conditions: 0.1 mmol/L metal ions, 24 h contact time, pH 4.0, 0.1 g biosorbent in 10 mL solution by using UV-Vis spectroscopy.

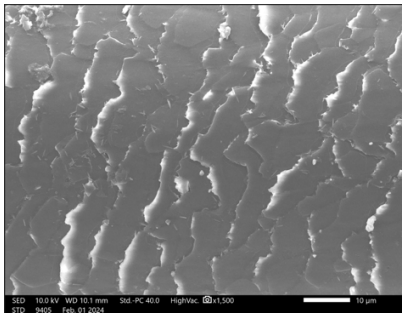
The adsorption experiment indicated that both untreated and chemically treated hair absorb significant amounts of heavy metals. Untreated hair absorbed 42% copper (Cu), and 40% lead (Pb). Notably, chemically treated hair had superior adsorption, removing 63% of Cu and 81% of Pb in formula 2. These findings support keratin's efficacy as a heavy metal adsorbent in formula 2 which each formula contain different concentration of EDTA.

4.2 SEM Analysis

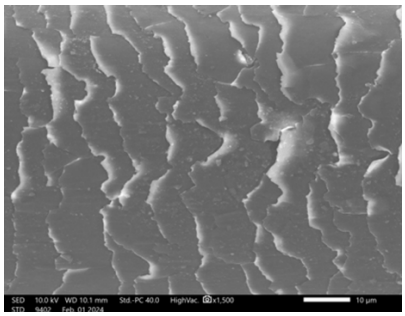
The SEM analysis revealed significant changes in the surface morphology of the hair samples following the adsorption process. The images revealed an increase in surface roughness, indicating that heavy metals were successfully adsorbing onto hair samples. A visual comparison of SEM images from untreated and treated hair samples confirmed heavy metal adsorption.



Control hair: SEM image of untreated hair showing the baseline surface morphology.



Hair after 50 cycles of absorption: SEM image displaying increased surface roughness and heavy metal adsorption after 50 absorption cycles.



Hair after 60 cycles of absorption: SEM image illustrating further increased surface roughness and continued heavy metal adsorption after 60 absorption cycles.

Figure 12. Scanning electron microscopy (SEM) images showing the surface morphology changes in hair samples due to heavy metal adsorption.

4.3 Device Efficiency

The device, which uses human hair as a filter material, was found to be effective at removing heavy metals from wastewater. The device's adsorption capacity was increased by applying a specialized coating to the hair. The integrated filter cartridge and cover system was effective in preventing hair loss and maximizing heavy metal removal. The efficiency of the hair-based filter was comparable to that of commonly used industry methods, laying the groundwork for the technology's future industrial applications.

5. Discussion

The results of this study indicate that human hair, both untreated and chemically treated, has significant potential as a biosorbent for heavy metals in wastewater. The adsorption capacities observed for copper (Cu), and lead (Pb) were particularly noteworthy, with chemically treated hair exhibiting superior adsorption compared to untreated hair. This supports the hypothesis that the structural properties of hair, specifically the presence of keratin and its constituent amino acid cysteine, can facilitate heavy metal sequestration.

These findings align with existing theories and published data on the use of biosorbents for heavy metal removal. The use of biosorbents has been widely studied due to their cost-effectiveness, availability, and environmental friendliness. The results of this study contribute to the growing body of evidence supporting the use of biosorbents, and specifically human hair, in addressing the global issue of heavy metal contamination in wastewater.

However, like any experimental study, there were potential sources of error and unexpected issues. Variability in the data could have arisen from differences in the hair samples, such as variations in hair type, age, and chemical treatment. Additionally, uncontrolled events such as changes in ambient temperature or pH could have affected the results. Future studies should aim

to control for these variables to ensure more consistent and reliable results.

In terms of future research directions, this study opens up several avenues. Further research could explore the use of different types of hair (e.g., animal hair) or different chemical treatments to enhance adsorption capacity. Additionally, scaling up the experiment to test the effectiveness of hair as a biosorbent in real-world wastewater treatment scenarios would be a valuable next step. The development of user-friendly devices like Hydrosense, which integrate hair-based filters for heavy metal removal, also presents exciting opportunities for practical application of this research.

In conclusion, this study provides a promising starting point for the use of human hair as a biosorbent in wastewater treatment. With further research and development, this could become a viable solution to the pressing issue of heavy metal contamination, benefiting communities worldwide.

6. Conclusion

This study demonstrates that human hair is an effective material for removing heavy metals from wastewater. Chemically treated hair removed even more heavy metals than untreated hair. This research supports the idea that hair, particularly the protein keratin it contains, can bind with heavy metals. These findings suggest that hair, a plentiful and often discarded resource, could be used in cost-effective and environmentally friendly filters for wastewater treatment. This has led to the development of the "Hydrosense" device as a practical example of how hair-based filters can be used to address the problem of heavy metal contamination in researcher area.

7. Acknowledgment

We are deeply grateful to Miss Phitchaphorn Prayoon-Anutep (Assumption College Thonburi, Bangkok, Thailand) for their invaluable guidance and support as our project advisor throughout the scientific process.

Reference

[1] Amlinger, F. (1996). Biowaste compost and heavy metals: a danger for soil and environment?. In The Science of Composting (pp. 314-328). Dordrecht: Springer Netherlands. https://www.statista.com/statistics/1302326/thailand-number-of-manufacturing-establishments/

[2] Dahiya, V. (2022). Heavy metal toxicity of drinking water: A silent killer. GSC Biological and Pharmaceutical Sciences, 19(1), 020-025.

[3] Statista Research Department. (2023, February 14). Thailand: Number of manufacturing establishments 2017-2022. Statista. https://www.statista.com/statistics/1302326/thailand-number-of-manufacturing-establishments/

[4] Industrial plant information for officers. (n.d.). Reg.diw.go.th. Retrieved February 16, 2024, from http://reg.diw.go.th/executive/thailand3.asp

[5] Kar, P., & Misra, M. (2004). Use of keratin fiber for separation of heavy metals from water. Journal of Chemical Technology & Biotechnology: International Research in Process, Environmental & Clean Technology, 79(11), 1313-1319.

[6] Poole, L. B. (2015). The basics of thiols and cysteines in redox biology and chemistry. Free Radical Biology and Medicine, 80, 148-157.

[7] Zhang, H., Carrillo-Navarrete, F., López-Mesas, M., & Palet, C. (2020). Use of chemically treated human hair wastes for

the removal of heavy metal ions from water. Water, 12(5), 1263.

[8] PR Water - Industrial and Ground Water. (n.d.). Heavy metals removal from wastewater.https://www.prwater.com.au/solution/water-treatment-heavy-metals-removal/

[9] Misra, M., Kar, P., Priyadarshan, G., & Licata, C. (2001). Keratin protein nano-fiber for removal of heavy metals and contaminants. MRS Online Proceedings Library, 70

[10] Hong, W. J., Shamsuddin, N., Abas, E., Apong, R. A., Masri, Z., Suhaimi, H., ... & Noh, M. N. A. (2021). Water quality monitoring with arduino based sensors. Environments, 8(1), 6.

Evaluation of Phytochemical Screening and Studies on chemical constituents from Methanolic Extracts of the *Shorea roxburghii* G. Don. Woods

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Abstract
Shorea roxburghii G. Don. is a plant in the dipterocarpaceae family, which is one of the medicinal plants that are native to Southeast Asia. The bark has a harsh taste and used in traditional medicine for ulcerative colitis. The flowers are used as an aromatic medicine, carminative, cardiotonic agents and antipyretics. The objectives of this research were to evaluate the preliminary phytochemical screening, isolate and elucidate of methanolic extracts from the stems of *S. roxburghii*. Phytochemical screening revealed the presence of tannins, flavonoids, saponins and terpenoids. The substances isolated by using the chromatography technique to separate the substances. This result indicated that four compounds were isolated by chromatographic techniques, and identified as *trans*-resveratrol (**1**), *trans*-ε-viniferin (**2**), and balanocarpol (**3**) and the mixture of β-sitosterol (4A) and stigmasterol (4B) The structures were determined based on spectroscopic data (1D, and 2D-NMR) and comparison with reported values.

Keyword: *Shorea roxburghii* G. Don., Phytochemical, chromatography technique, spectroscopy technique

1. Introduction

Pa-yom (*Shorea roxburghii* G. Don.) belongs to the Dipterocarpaceae family. In Thailand, 27 species of the Shorea genus have been reported [1]. The Pa-yom tree is native to Thailand and Asia. It is a medium to large-sized deciduous tree, growing approximately 15–30 meters tall. Its bark is dark gray and furrowed. The leaves are simple, alternately arranged, oblong in shape with rounded or short-tipped ends and rounded bases. The flowers are white, highly fragrant, and bloom in large clusters along branches and at the branch tips. The fruit is oval-shaped.

The *S. roxburghii* tree has numerous medicinal properties according to local wisdom. For example, theflowers, which have a fragrant and mellow taste, can be used to make medicine for treating wind-related illnesses, strengthening the heart, and reducing fever. The bark, which has an astringent taste, can be boiled and drunk to treat diarrhea and intestinal inflammation. It can also be ground and applied to wounds to promote healing, cleanse wounds, and treat rashes and itching. The young shoots and bark can be used as astringent agents, in cold medicines for fever, and to treat internal heat [2]. Most of the compounds found in plants of the Dipterocarpaceae family are phenolic compounds such as oligostilbenoids, flavonoids, phenyl propanoids, and other compounds like steroids and terpenoids [3]. The compounds found in *S. roxburghii* have significant biological activities, such as anti-skin cancer effects from the bark [4], anti-inflammatory and antioxidant properties [5],

anti-hyperglycemic and anti-hyperlipidemic effects [6], and the ability to prevent chemotherapy-induced peripheral neuropathy [7]. Due to the interesting biological activities and the diversity of compounds found in plants of the Dipterocarpaceae family, along with numerous research reports on the biological activities and chemical composition of *S. roxburghii*, studies on the preliminary phytochemical screening of extracts from this plant, including the chemical composition of its wood, are still limited in Thailand. Therefore, this research aims to investigate the preliminary phytochemical screening, isolate, and elucidate the structures of pure compounds from the methanol extract of *S. roxburghii* wood. Four compounds were found: three stilbenoid derivatives, as *trans*-resveratrol (**1**), *trans*-ε-viniferin (**2**), and balanocarpol (**3**), and a mixture of β-sitosterol (**4A**) and stigmasterol (**4B**). The study results will provide additional information on the compounds found in *S. roxburghii* wood and facilitate the development of extracts for medical, pharmaceutical, and cosmetic applications. This also promotes the value of *S. roxburghii* and supports the conservation of plant species in the future.

2. Methods

2.1 Sample Preparation and Extraction

The wood samples of *S. roxburghii* G. Don. used in this experiment were collected from Phra Saeng District, Surat Thani Province, in December 2023. The bark was removed, and the wood was ground using a hammer mill, then dried in a hot air oven at 45 °C for 24 hours, yielding a dry weight of 1.08 Kg. The dried wood was then extracted by soaking in 5 L of methanol for 5 days. The mixture was filtered using filter paper No. 1, and the soaking process was repeated with the same method. The solvent was evaporated using a rotary evaporator under vacuum, yielding 70.70 g. of crude methanol extract. The yield was calculated on a dry weight basis using the formula:

$$\%\text{Yield} = [A/B]\times 100$$

Where : A = the weight of the extracted substance (g).
B = the initial weight of the herbal raw material used (g).

2.2 Preliminary Phytochemical Screening

The preliminary phytochemical screening was conducted based on the technique of Koodkaew, I. et al. [8] using the coloring identification test, which observes the color change of the sample compared to the control. The tests were conducted as follows:

2.2.1 Tannin Test

0.2 g of crude extract were mixed with 5 ml of distilled water and boiled for 2 min. The mixture was filtered using filter paper No. 1, and the filtrate was treated with 2-3 drops of 1% $FeCl_3$ solution. The presence of tannins was indicated by a greenish-brown or dark blue color.

2.2.2 Flavonoid Test

0.2 g of crude extract were extracted with 3 ml of 50% methanol solution and filtered using filter paper No. 1. Small pieces of magnesium wire (2-3 pieces) were added to the filtrate, which was then boiled and left to cool. Concentrated HCl (1-3 drops) was added. The presence of flavonoids was indicated by a pink, orange, or red color.

2.2.3 Alkaloid Test

0.2 g of crude extract were mixed with 1 ml of 10% H_2SO_4 solution, shaken, and heated for 2-3 min. The mixture was filtered using filter paper No. 1, and the filtrate was treated with 5 drops of Dragendorff's

reagent. The presence of alkaloids was indicated by an orange-red precipitate.

2.2.4 Saponin Test

0.2 g of crude extract were mixed with 5 ml of distilled water, boiled, and filtered using filter paper No. 1. The filtrate was then vigorously shaken. The presence of saponins was indicated by the formation of froth.

2.2.5 Terpenoid Test

0.2 g of crude extract were mixed with 2 ml of chloroform and shaken. Concentrated H_2SO_4 was then slowly added. The presence of terpenoids was indicated by the formation of a layer.

2.2.6 Cardiac Glycoside Test

0.2 g of crude extract were dissolved in methanol, and 3 drops of acetic acid and 3 drops of concentrated H_2SO_4 were added. The presence of cardiac glycosides was indicated by a blue, green, or red color.

2.3 Purification of Compounds

20.5 g of crude methanol extract were separated using column chromatography (CC) with silica gel (silica gel 60 (Merck, 70-230 mesh)) as the stationary phase and hexane and dichloromethane (CH_2Cl_2) in a ratio of 3:7 as the mobile phase. The compounds were monitored using Thin-Layer Chromatography (TLC) by measuring UV absorption at wavelengths of 254 and 366 nm, and spray reagents such as vanillin spray reagent and anisaldehyde were used for detection. Four pure compounds were isolated: *trans*-resveratrol (**1**; 23.4 mg.) *trans*-ε-viniferin (**2**; 2.1 mg) balanocarpol (**3**; 10.1 mg) and a mixture (214.7 mg) of β-sitosterol (**4A**) and stigmasterol (**4B**)

3. Results and Discussion

3.1 Extraction of Samples

The extraction of *S. roxburghii* wood samples yielded a percentage yield (%Yield) of 6.50% by weight. The crude extract obtained was dark brown, viscous, and had a distinctive odor, as shown in Figure 1.

Figure 1: Characteristics of crude methanol extract from *S. roxburghii* wood.

Using methanol as the solvent, a preliminary chemical analysis of *S. roxburghii* wood extract revealed substances from 4 chemical groups: tannins, flavonoids, saponins, and terpenoids, as shown in Table 1.

Table 1: Preliminary chemical compounds from crude methanol extract of *S. roxburghii* wood.

Chemical class	Observation
Tannins	+
Flavonoids	+
Alkaloids	-
Saponin	+
Terpenoids	+
Cardiac glycosides	-

Note: (-) not observed, (+) observed

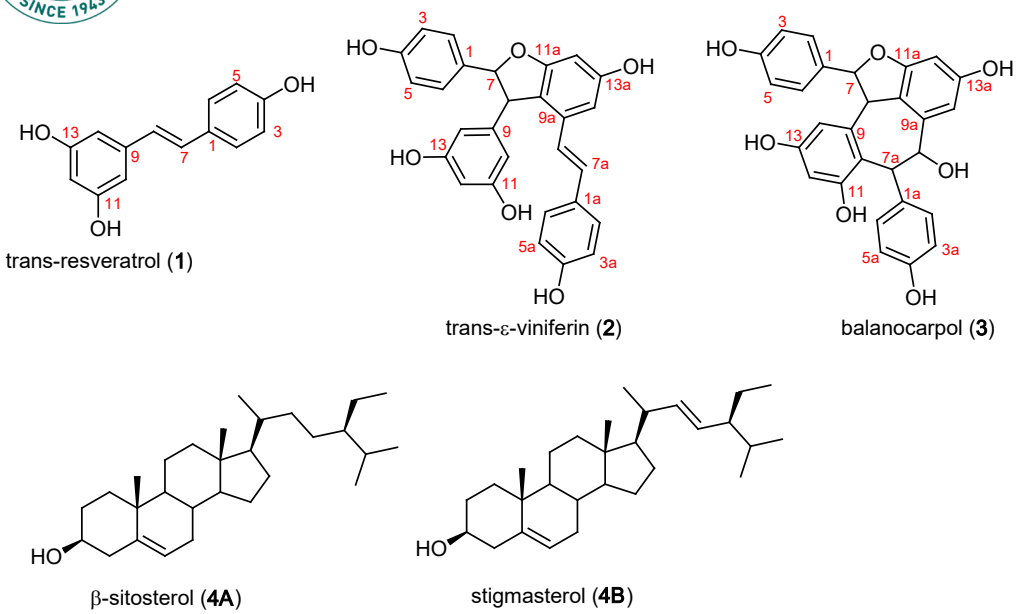

Figure 2. Structures of compounds **1**–**4**

3.3 Purification of Compounds

From the literature review, it was found that the major compounds separated from *S. roxburghii* wood are stilbenoids. In this study, four compounds were purified including three derivatives of stilbenoid compounds: *trans*-resveratrol (**1**), *trans*-ε-viniferin (**2**), and balanocarpol (**3**), along with a mixture of β-sitosterol (**4A**) and stigmasterol (**4B**). Compounds 1-3 share similar UV absorption characteristics.

Compound **1** from the ^{1}H NMR spectrum data (Table 2) shows signals of 1,4-disubstituted benzene at δ_H 6.72 and 7.29 (each d, J = 8.4 Hz), 1,3,5-trisubstituted benzene at δ_H 6.14 (t, J = 2.0 Hz, H-12) and 6.41 (d, J = 2.0 Hz, H-10 and H-14), and signals of *trans* olefinic at δ_H 6.76 and 6.89 (each d, J = 16.4 Hz, H-8 and H-7). Upon comparison with reported spectra, compound **1** corresponds to *trans*-resveratrol [9].

Compound 2 from the ^{1}H-NMR spectrum data (Table 2), upon comparison with compound 1 (*trans*-resveratrol), exhibits similar signal characteristics but differs in having additional signals of 1,4-disubstituted benzene and 1,2,3,5-tetrasubstituted benzene, each comprising one set of signals. Additionally, signals of oxymethine proton at δ_H 5.29 (δ_C 93.0; H-7) and methine proton at δ_H 4.35 (δ_C 56.2; H-8) with a trans vicinal coupling constant (J=5.2 Hz) are observed. Based on HMBC spectrum data, the oxymethine proton at δ_H 5.29 (H-7) correlates with carbons C-2, C-6, C-9, C-10a, and C-11a; δ_H 6.58 (H-8a) correlates with carbons C-1a, C-10a, and C-14a; and δ_H 6.78 (H-7a) correlates with carbons C-2a, C-6a, and C-9a (Figure 3). This confirms that compound **2** is formed by connecting two *trans*-resveral 2 structures fused into a furan ring. Upon comparison of the ^{1}H NMR spectrum with previously reported compounds, compound **2** corresponds to *trans*-ε-viniferin [9].

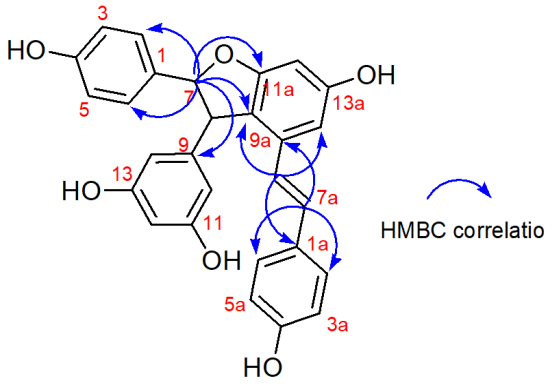

Figure 3. Important HMBC correlations of compound **2**

Table 2 ^{1}H and ^{13}C NMR (400 and 125 MHz, acetone-d_6) spectroscopic data of compounds **1**–**3** in acetone-d_6 (δ in ppm, multiplicities, J in Hz)

Position	compound **1**		compound **2**		compound **3**	
	δ_H	δ_C	δ_H	δ_C	δ_H	δ_C
1	-	129.9	-	133.0	-	132.7
2, 6	7.29 d (8.4)	128.8	7.07 d (8.8)	127.0	7.47 d (8.6)	129.7
3, 5	6.72 d (8.4)	116.3	6.70 d (8.8)	115.3	6.93 d (8.6)	115.6
4	-	158.1	-	157.3	-	157.7
7	6.89 d (16.4)	129.0	5.29 d (5.2)	93.0	5.16 d (9.3)	51.5
8	6.76 d (16.4)	126.7	4.35 d (5.2)	56.2	5.72 d (9.3)	92.7
9	-	140.8	-	146.6	-	142.0
10	6.41 d (2.0)	105.6	6.11 s	106.1	-	119.6
11	-	159.5	-	159.0	-	156.6
12	6.14 t (2.0)	102.6	6.11 s	101.2	6.02 d (2.0)	101.0
13	-	159.5	-	159.0	-	156.0
14	6.41 d (2.0)	105.6	6.11 s	106.1	5.98 d (2.0)	105.9
1a			-	129.2	-	132.6
2a, 6a			7.05 d (8.8)	127.8	6.71 d (8.6)	130.7
3a, 5a			6.61 d (8.8)	115.4	6.44 d (8.6)	113.4
4a			-	157.3	-	154.9
7a			6.78 d (16.4)	129.0	5.40 d (2.0)	72.4
8a			6.58 d (16.4)	122.6	4.88 d (2.0)	49.4
9a			-	135.5	-	139.9
10a			-	118.9	-	112.9
11a			-	161.6	-	158.8
12a			6.20 d (2.0)	95.9	6.19 d (2.0)	94.2
13a			-	158.7	-	158.3
14a			6.60 d (2.0)	103.3	6.18 d (2.0)	103.6

Compound **3**, as observed from the ^{1}H and ^{13}C-NMR spectra (Table 2), shows similar signal characteristics to compound **2**, *trans*-ε-viniferin. However, they differ in that compound **3** lacks trans olefinic proton signals but instead exhibits a single set of oxymethine signals at δ_H 5.40 (d, J = 2.0 Hz, H-8a) and methine protons increased by one set at δ_H 4.88 (d, J = 2.0 Hz, H-7a). These are connected in the structure as confirmed by HMBC spectrum data, where the oxymethine proton at δ_H 4.88 (H-7a) correlates with carbons at δ_C 72.4 (C-8), 119.6 (C-10), 130.7 (C-2a,6a), 132.6 (C-1a), 142.0 (C-9), 139.9 (C-9a), and 156.6 (C-11), while the oxymethine proton at δ_H 5.40 (H-8a) correlates with carbons at δ_C 103.6 (C-14a), 112.9 (C-10a), 119.6 (C-10), 132.6 (C-1a), and 139.9 (C-9a) (Figure 4). From the data, it is confirmed that compound **3**, located at positions C-10 and C-7a, forms a fused 7-membered ring structure. Upon comparison of the 1H NMR spectrum with reported data, compound 3 is identified as balanocarpol [10].

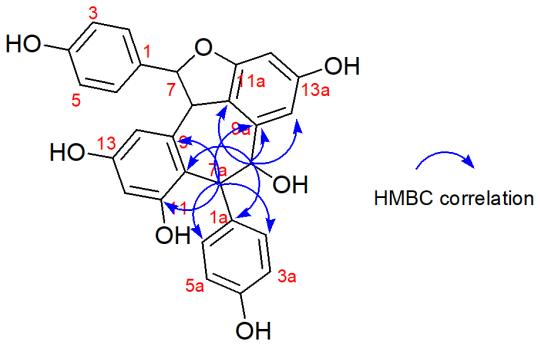

Figure 4. Important HMBC correlations of compound **3**

4. Conclusion

From the extraction of wood using methanol, the extracted substance weighed 70.70 grams, yielding 6.50% based on the weight of the raw material. Preliminary chemical analysis identified four types of phytochemicals: tannins, flavonoids, saponins, and terpenes. The separation and structural confirmation of substances revealed a total of four purified compounds. Based on NMR data and comparison with reported information, compound **1** was identified as *trans*-resveratrol, compound **2** as *trans*-ε-viniferin, compound **3** as balanocarpol, and compound **4** as a mixture of β-sitosterol and stigmasterol. Therefore, this research provides insights into the separation and structural elucidation of compounds from agarwood. It highlights the potential biological properties of these purified substances, such as anti-inflammatory and antioxidant properties, which are relevant for future applications in pharmaceuticals and cosmetics.

ACKNOWLEDGMENTS

The authors thank for faculty of pharmaceutical sciences, Burapha University for providing laboratory facilities and finance in this research. We would like to thank the Faculty of Science and Technology, Rajamangala University of Technology Tawan-OK for partial support of equipment.

Reference

[1] Smitinand Tem. 2014. Forest Herbarium, Royal Forest Department, Bangkok, 806 pp.

[2] Medthai. 2020. Pa-yom: 16 Benefits and Uses of Pa-yom!. From https://medthai.com/%e0%b8%9e%e0%b8%b0%e0%b8%a2%e0%b8%ad%e0%b8%a1/, 26 June 2024.

[3] Abdullahi Musa, Nanik Siti Aminah, Alfinda Novi Kristanti, Imam fathoni, Rizka Tazky Amalia, Tin Myo Thant, P. Rajasulochana and Yoshiaki Takaya. 2024. Phytochemical and pharmacological profile of genus shorea: A review of the recent literature, Heliyon, Volume 10, e23649.

[4] Hiroyuki Moriyama, Mariko Moriyama, Kiyofumi Ninomiya, Toshio Morikawa, and Takao Hayakawa. 2016. Inhibitory Effects of Oligostilbenoids from the Bark of *Shorea roxburghii* on Malignant Melanoma Cell Growth: Implications for Novel Topical Anticancer Candidates. Bio. Pharm. Bull. Volume 39 No. 10, p. 1675-1682.

[5] Jun Hu, Changjun Tong, Jiajun Zhou, Chaoqing Gao and Opeyemi Joshua Olatunji. 2022. Protective Effects of *Shorea roxburghii* Phenolic Extract on Nephrotoxicity Induced by Cyclophosphamide: Impact on Oxidative Stress, Biochemical and Histopathological Alterations. Chemistry & Biodiversity, Volume 19, No. 5.

[6] Emmanuel Ayobami Makinde, Nisaudah Radenahmad, Raihan Uz Zaman and Opeyemi Joshua Olatunji. 2020. Fatty

Acids and Sterol Rich Stem Back Extract of *Shorea Roxburghii* Attenuates Hyperglycemia, Hyperlipidemia, and Oxidative Stress in Diabetic Rats. European Journal of Lipid Science and Technology. Volume 122, 2000151.

[7] Haili Wang, Opeyemi Joshua Olatunji and Na Xue. 2021. Antinociceptive, Anti-Hyperalgesia and Antiallodynic Activities of Polyphenol Rich Extract from *Shorea roxburghii* against Cyclophosphamide Induced Peripheral Neuropathy. Chemistry & Biodiversity. Volume 18, No. 10, e2100415.

[8] Intira Koodkaew, Kanokrat Boonraksa and Natchana Sengseang. 2018. Preliminary phytochemical determination and phytotoxic effects of *Mimosa pudica* L. leaf crude extract. Khon Kaen agriculture journal. volume 46, p. 129-136.

[9] Mats Kiene, Malte Zaremba, Hendrik Fellensiek, Edwin Januschewski, Andreas Juadjur, Gerold Jerz and Peter Winterhalter. 2023. In Silico-Assisted Isolation of trans-Resveratrol and trans-ε-Viniferin from *Grapevine Canes* and Their Sustainable Extraction Using Natural Deep Eutectic Solvents (NADES). Foods, Volume 12, p. 4184.

[10] Sri Atun, Nurfina Aznam, Retno Arianingrum and Masatake Niwa. 2006. Balanocarpol and heimiol a, two resveratrols dimer from stem bark *Hopea mengarawan* (Dipterocarpaceae). Indonesian Journal of Chemistry, Volume 6, No. 1, p. 75–78.

[11] Hisashi Kojima, Noriko Sato, Akiko Hatano and Haruo Ogura. 1990. Sterol glucosides from *Prunella vulgaris*. Phytochemistry, Volume 29, No. 7, p. 2351-55.

Biopolymeric blended formulations and computational simulations for sustainable development: Biowaste material

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Abstract

The increasing global demand for sustainable strategies paves the new paths for exploring innovative approaches for the valorization of bio-waste has boosted chitin which is hard nitrogenous polysaccharide is the major source of pollution in coastal areas. These waste bio-material derivatives are promising as drug delivery applications and it is economically more feasible and have enormous application in pharmaceutical field. The research targets at producing Curcumin loaded chitosan-tripolyphosphate nanoparticles experimentally by a novel technique based on ionic gelation technique using tripolyphosphate (TPP) as cross-linking agent and it is encapsulated with curcumin a bio-active compound from *curcuma longa*. The biomass is subjected for characterization studies IR, UV, TEM, SEM, XRD and antibacterial studies using Micrococcus luteus and Vibrio cholerae. The efficacy of chitosan -tripolyphosate loaded with curcumin is evaluated computationally by Swiss target predictions, bioavailability radar, Blood Brain Barrier penetration, toxicity predictions and molecular docking. The encapsulated product can be used in drug delivery application and can be subjected to further applications in future.

Keywords: ***Chitosan-tripolyphosphate, Curcumin, anti-bacterial studies, computational studies***

1. Introduction

The total world fisheries and aquaculture production showed enormous growth, reaching 178 million and above, and representing an expansion of 52 million tons each year. Of the total production, molluscs comprised 13%, while crustaceans comprised 9% [1]. Every year, close to 8 million tons of waste crab, shrimp and lobster shells are produced globally, comprising up to 60% of overall crab mass [2]. On top of that, over 10 million tons of shells are produced each year, of which over 70% is represented by oyster, clam, scallop and mussel shells [3]. Mollusc shells account for 65–90% of live weight, depending on the species [4,5]. Mussels in particular have the greatest increase in production and shell contribution compared to other shellfish species [6]. A significant portion relates also to abalone and other gastropod shells [7]. Shells can be turned for the production of bioactive material for efficient pharmacological activity.

The main objective of this journal is thus to provide a useful biopolymeric blended material for sustainable development and to characterize the understanding complexity of shell reutilization; and to investigate their valorization and to add a bioactive antioxidant curcumin for effectiveness which relates its options in terms of bioeconomy prerequisites, via laboratory experiments and computational simulations.

2. Materials and methods

Crab shell was obtained from Coimbatore, Tamil Nadu, India. Tripolyphosphate (TPP) (technical grade, 85%), curcumin purchased Arjuna Natural

Pvt Ltd. Ethanol, Acetic acid, NaOH (50% & 70%). All other chemicals used in study were of analytical grade and deionized water was used for all experimental protocols. The crab was washed with tap water to remove possible foreign materials present (dirt and sands). The commercial chitosan was from Sigma-Aldrich (purity 99%).

2.1.1Production of Chitosan - Experimentally

Isolation of chitosan from crab shell wastes involves four traditional steps; de-proteinisation (DP), de-mineralization (DM), de-colourization (DC), and de-acetylation (DA). The wet crab was washed and dried followed by grinding and sieving to a particle size of 750 µm, and then placed in a plastic bottle for storage at ambient temperature until used. De-proteinisation (DP) was then carried out on the crab shells. Four hundred grams of crab shell was place in a solution of 3.5% NaOH (w/v) for 2 h at 65 °C, solid: solvent (1:10, w/v), then the solid was separated from the liquid and washed with distilled water until absence of colour in the medium which represents the absence of protein. The next step was to demineralise the shells. The deproteinised shell was placed in 1 N HCl for 30 minutes at room temperature, solid: solvent (1:15, w/v). Subsequently, the liquid was decanted and the solid was washed with distilled water until neutral pH, the remaining was dried at 50 °C for 12 hr. and the product was chitin. The chitin was decolorized with 0.315% sodium hypochlorite (NaOCl) (w/v) for 5 minutes at room temperature solid: solvent (1:10, w/v) was poured into the vessel containing the solid and the suspension was agitated until the pigmentation of the solid disappeared. The white solid (chitin) was washed and dried at 50 °C for 12 hr in the oven. The de-acetylation of chitin was carried out by mixing chitin with 50% NaOH for 30 min at 121^0C, solid: solvent (1:10, w/v). The mixture was washed with distil water several times to remove residual sodium hydroxide, until pH 7 was achieved. The chitosan was dried in an oven at 50 ºC for 18 hr. [8]

Formation of chitosan-tri polyphosphate nanoparticles

Chitosan, 1mg/ml was dissolved in 1% (w/v) acetic acid and allow the solution became transparent. The addition of tri polyphosphate solution, at a concentration of 1 mg/mL, to Chitosan solution, with stirring at room temperature, produced the formation of chitosan-tri polyphosphate nanoparticles by ionic gelation mechanism

Preparation of curcumin encapsulated chitosan nano particles

Chitosan nanoparticles were prepared according to ionic gelation technique. Chitosan solution (1 mgml) was prepared by dissolving chitosan in acetic acid and the solution was stirred overnight at room temperature. Tripolyphosphate (TPP) was dissolved in water to reach a final concentration of 1mgml. Curcumin solution was also prepared at a concentration of 1mgml by dissolving curcumin in ethanol. To prepare loaded nanoparticles, chitosan solution was pipetted into a 10ml round–bottom flask and stirred using magnetic stirrer. Curcumin loaded chitosan-tripolyphosphate nanoparticles were prepared by taking an appropriate volume of curcumin solution containing 10 wt.% of chitosan. Curcumin and TPP solutions were mixed together shortly before the addition of this mixture to chitosan solution. Afterwards, the nanoparticle suspension was left to stir under dark conditions until the complete evaporation of ethanol. The final solution was centrifuged for 15 minutes and dried.

2.1.2 Retrieval of protein - Computational Simulation

The diabetic trans membrane glycoprotein, dipeptidyl peptidase 4 (DPP4), with the Protein Data Bank (PDB) ID 1J2E, has been downloaded from the RCSB PDB database in .pdb format. This format contains detailed three-dimensional structural

information critical for understanding the protein's function and interactions, aiding in the development of therapeutic inhibitors for diabetes management [9].

2.1.3 Retrieval of ligands

The selection process utilized the IMPPAT (Indian Medicinal Plants, Phytochemistry, and Therapeutics) database to identify potential ligands with relevant bioactive properties [10]. The canonical SMILES (Simplified Molecular Input Line Entry System) representations of all the selected ligands were compiled and tabulated for further analysis. Additionally, the top three ligands, based on their pharmacological relevance, were retrieved from the PubChem database in .sdf (Structure Data File) format for detailed structural and functional studies. This approach facilitates a comprehensive understanding of the molecular interactions and therapeutic potential of chitosan and curcumin compounds.

2.1.4 Swiss ADME analysis

The SWISS ADME analysis [11] have been tabulated, provides overview of the bio availability radar for each compound, which predicts the drug-likeness of these small molecules. The pink area in the bioavailability radar indicates the oral bioavailability of the drug. The analysis assesses various physicochemical properties including lipophilicity, polarity, insolubility, size, flexibility, and instauration. Additionally, pharmacokinetic and medicinal chemistry properties were analyzed, and the BOILED-Egg model was generated to further evaluate drug absorption and brain penetration potential.

2.1.5 Target prediction

Depending on 2D and 3D comparability against the library database, the Swiss Target Prediction website [12] predicts the most plausible bioactive macromolecular targets for the queried small molecule. This prediction is based on the structural similarity of the small molecule to known bioactive compounds, enabling the identification of potential targets. The tool enhances our understanding of the molecular interactions and aids in drug discovery by providing insights into the likely biological targets.

2.1.6 Drug likeness and bio-activity score

The effectiveness of the ligand molecule against specific target enzymes, including GPCR ligands, ion channel modulators, kinase inhibitors, nuclear receptor ligands, protease inhibitors, and other enzyme targets crucial in metabolic processes, was studied using the bioactivity score from MOLINSPIRATION [13]. This analysis provides insights into the potential efficacy of the ligand by evaluating its interaction with these key enzymes, which play vital roles in various biological functions and metabolic pathways.

2.1.7 Toxicity prediction

The toxicity of the small molecules was predicted using the virtual lab tool ProTox-II [14]. This tool determines the toxic dose, expressed as LD50 in mg/kg of body weight. Drug molecules are then classified into six toxicity classes based on their LC50 values, ranging from Class 1 (most toxic) to Class 6 (least toxic). This classification provides a detailed assessment of the potential toxicity of the compounds, aiding in safety evaluations

2.2 Molecular docking

The protein 1J2E was downloaded in pdb format from the RCSB PDB database for detailed analysis. Based on their pharmacological importance and drug-likeness properties, the top three ligands were selected for further study. These ligands were initially in .sdf format and were converted to .pdb format using the OPENBABEL Chemical file format converter. Following conversion, each ligand was individually docked against the 1J2E protein using the Patchdock webserver [15], which provides an efficient algorithm for molecular docking. The conformation with the highest docking score was then downloaded in .pdb format. To visualize the molecular interactions, a 2D interaction diagram was generated using the

Poseview plugin available on the ProteinsPlus structure-based modeling support server [16].

3. Results and Discussion

3.1 TEM Analysis Chitosan – TPP curcumin encapsulated chitosan nanoparticle

Transmission Electron Microscopy (TEM) images of Chitosan–TPP curcumin encapsulated chitosan nanoparticle composite shown in figure:1. These particles observed as spherical in shape and evenly dispersed. Chi-TPP were observed as hollow spherical nanoparticles and curcumin Nano composites appeared as dark solid spherical particles indicating entrapment of curcumin inside hollow spherical capsule.

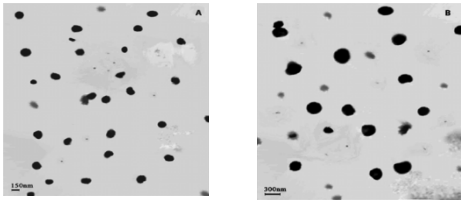


Fig: 1 represents the TEM analysis of Chitosan–TPP curcumin encapsulated nanoparticle

3.2 SEM Analysis of Chitosan–TPP curcumin encapsulated chitosan nanoparticle

The particle size data of curcumin TPP-chitosan NPs SEM is shown in Fig:2 images show that the nanoparticles with spherical morphology. From the SEM images it is also clear that the prepared NPs have a smooth surface with spherical morphology.

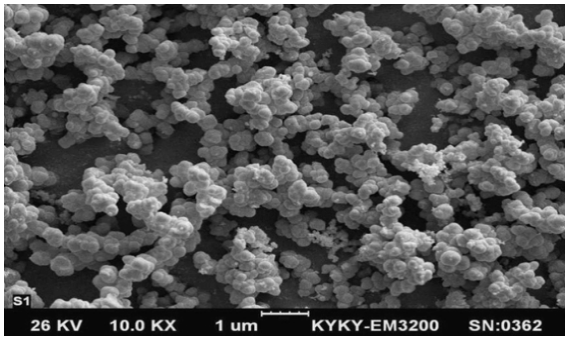
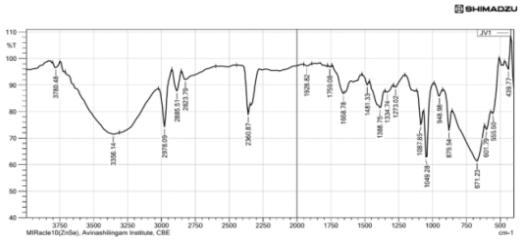


Fig : 2 represents the SEM analysis of Chitosan–TPP curcumin encapsulated nanoparticle

3.3 FT-IR Spectrum



The FT-IR spectra of curcumin loaded TPP-chitosan NPs a peak at 1658 cm-1 was observed and this corresponds to amide I bending vibration. The phosphate groups of TPP produces a number of vibrational bands in the region of 1928–1759 cm-1 as shown in the spectrum. The change in wave number of the peaks in these regions indicates that there is an interaction between the two groups. In the spectra of curcumin TPP–chitosan NPs , a peak at 1481 cm-1 was observed which corresponds to –NH deformation and a change in the peak at 1049 cm-1 correspond to keto group of the curcumin which is showm in Fig :3

Fig: 3 represents FT- IR spectrum of Chitosan–TPP nanoparticle and curcumin encapsulated

3.4 UV Spectrum

UV-Vis spectroscopy used for the determination of electronic transition. UV-Vis spectrum of curcumin encapsulated chitosan nano particle shows a peak at 424 nm. This peak shows that the maximum amount of curcumin encapsulated inside the chitosan nano particle which is shown in fig:4

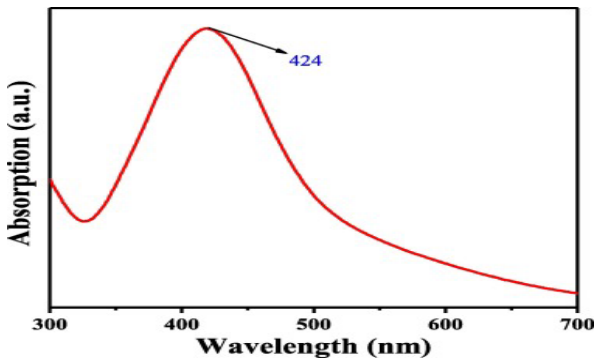


Fig: 4 represents UV analysis of Chitosan–TPP curcumin encapsulated chitosan nanoparticle

3.5 XRD Spectrum
Particle Size Calculation

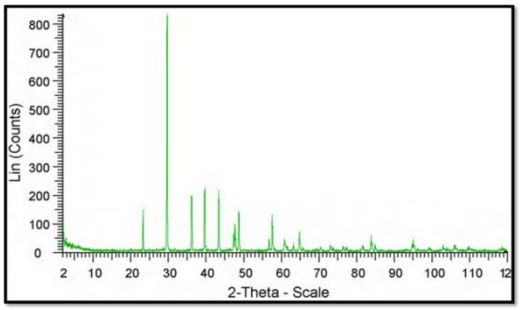


Fig: 5 represents the XRD analysis of Chitosan–TPP nanoparticle and curcumin encapsulated

From this spectrum fig :5, considering the peak at degrees, average particle size has been estimated by using Debye-Scherrer formula,

$$D = 0.9 \times \lambda / \beta \cos \theta$$

Where 'λ' is wave length of X-Ray (0.1541 nm), 'β' is FWHM (full width at half maximum), 'θ' is the diffraction angle and 'D' is particle diameter size.

Peak position 2θ= 29.5
Full Width at Half Maximum (FWHM) = 0.6

Wavelength = 0.15418
β = 0.6 x (3.14/180)
=0.01466
Cos θ = cos(14.75)
=0.967045
D = 0.9 x 0.15418 / (0.01466 x 0.967045)
= 9 nm

3.6 Antibacterial efficacy of Curcumin encapsulated Chitosan-TPP nanoparticles

The analyzed against Vibrio cholera and Micrococous luteus. Curcumin treated bacterial culture of Micrococous luteus and Vibrio cholerae showed zone of inhibition of 28 and 35 ppm shown in table 1 respectively

Table: 1 Antibacterial efficacy of Curcumin encapsulated Chitosan-TPP nanoparticles

S. No	Organism	Zone of Inhibition	
		STD CIPROFLOXACIN (10 micro g/disc)	SAMPLES (100 micro g/ disc)
1	Vibrio cholerae	46	35
2	Micrococcus luteus	37	28

3.7 Computational simulation

The chitosan and curcumin were further studied computationally for the efficacy of chitosan-tripolyphosate loaded with curcumin is evaluated computationally by Swiss target predictions, bioavailability radar, Blood Brain Barrier penetration, toxicity predictions and molecular docking techniques.

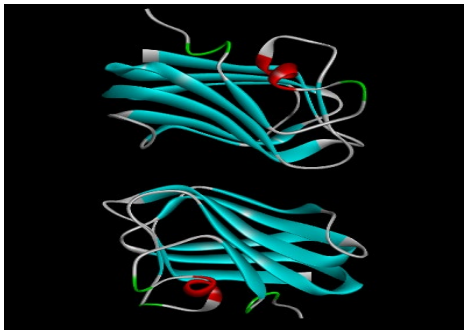


Fig : 6 represents the 3D structure of Chitosan

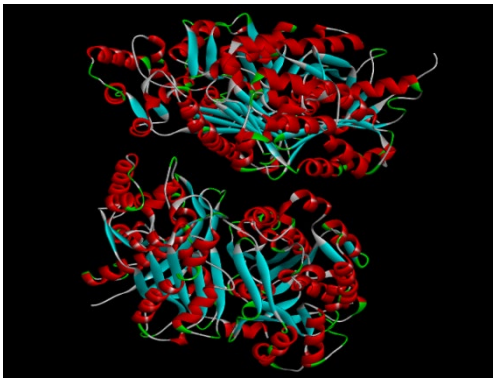


Fig : 7 represents the 3D structure of Chitosan

3.8 Bioavailability radar

The Bioavailability radar of chitosan and curcumin is ahown in fig 8,9 where the unsaturation,flexibility,liposity,size ,polarity and insolubilty of the bioactive compounds were studied.

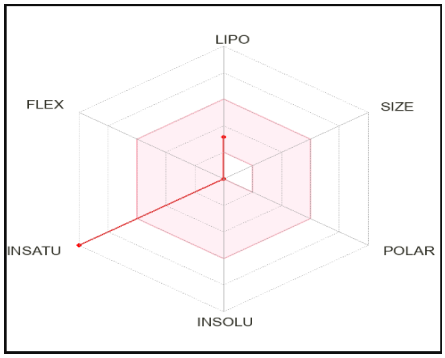


Fig: 8 Schematic representation of Bioavailability radar of chitosan

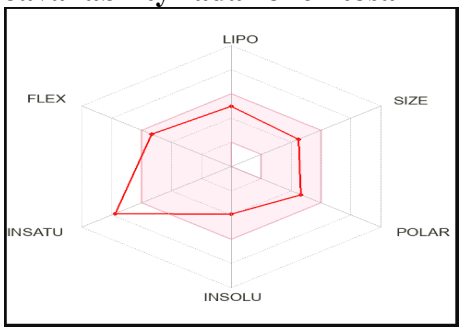


Fig 9 Schematic representation of Bioavailability radar of curcumin

3.9 Hydropathy Plot for Chitosan and curcumin

The hydrophobic and hydrophilic features of the chitosan and curcumin is shown in fig : 10,11

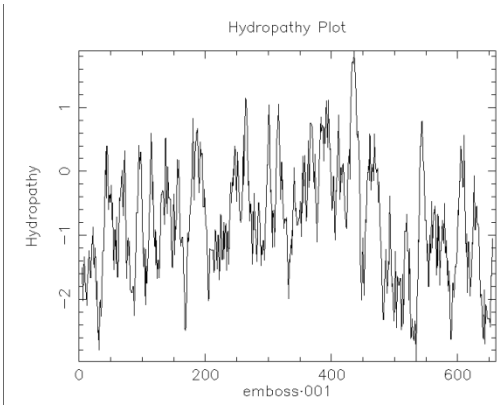


Fig:10 represents the chitosan hydropathy plot

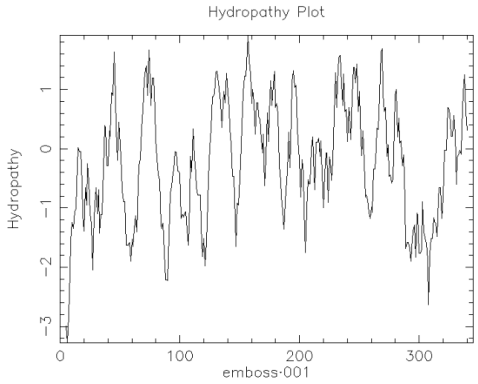


Fig:11 represents the curcumin hydropathy plot

3.10 SWISS Target Predictions

The swiss target predictions of the Chitosan and Curcumin is studied which predicts the probability of target which is shown in fig:12,13 respectively.

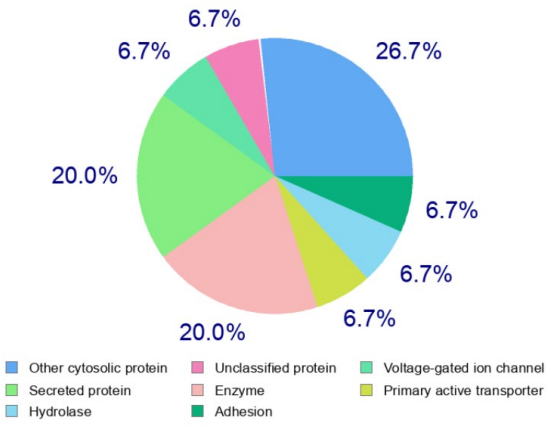


Fig:12 represents the Swiss target prediction of chitosan

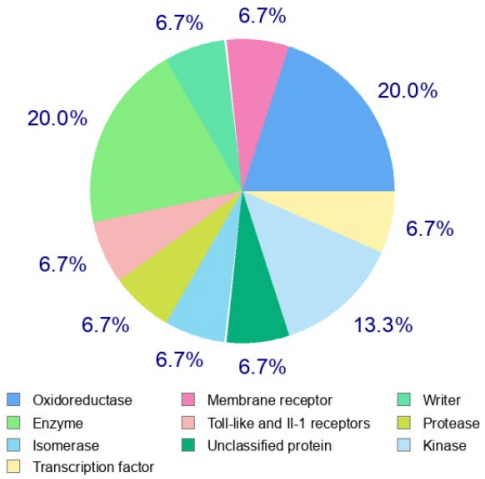


Fig:13 Swiss target prediction of curcumin

3.11 Blood Brain Barrier

The BBB studies were conducted for the toxicity studies were the high, low risk factors of toxicity were analyzed by egg model representation and it is shown in the fig: 14

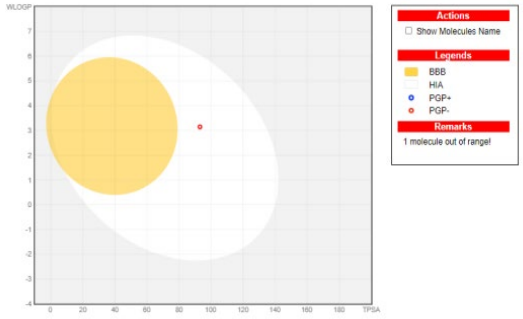


Fig:14 Schematic representation of Gastrointestinal absorption and Blood-Brain Barrier (BBB) penetration using BOILED-Egg

3.12 Molecular Docking Studies

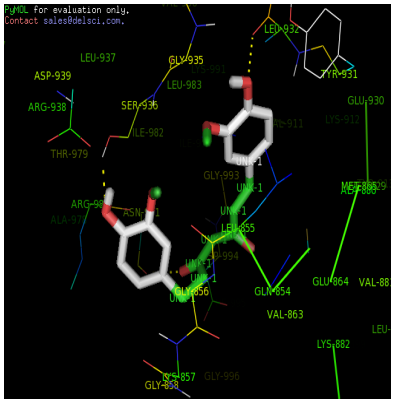


Fig:15 represents the docked Conformation showing interactions between curcumin encapsulated chitosan nano particle and JAK-2 Protein

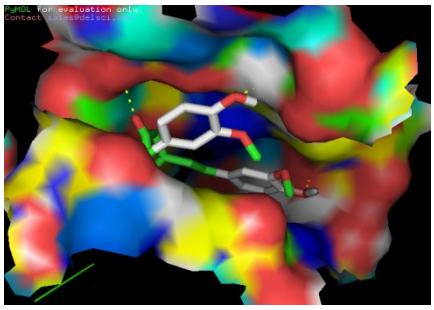


Fig16:represents the Docked Conformation in surface representation showing interactions between Curcumin and JAK-2 Protein

4.Conclusion

The present work demonstrates a method in producing Curcumin encapsulated chitosan nanoparticles and it is characterized by various techniques experimentally and it is tested against Micrococous Luteus gram positive bacteria and Vibrio Cholerae gram negative bacteria. Curcumin loaded chitosan-tripolyphosphate nanoparticles has shown significant increased zone of inhibition. The chitosan and curcumin which predicted computationally shows excellent target predictions by Swiss target predictions, bioavailability radar, Blood Brain Barrier penetration, toxicity predictions and molecular docking techniques. The molecular docking techniques has been carried further upon JAK2 expression inhibiting as an important Pharmacological activity, because

of its role in breast cancer. JAK2 is Janus Kinase-2 which supports breast cancer growth and inhibition of it will control cancer growth.

REFERENCES

[1] Food and Agriculture Organization of the United Nations. World Food and Agriculture—Statistical Yearbook 2021; Food & Agriculture Organization: Rome, Italy, 2021; ISBN 978-92-5-134332-6. [Google Scholar]

[2] Yan, N.; Chen, X. Sustainability: Don't Wa ste Seafood Waste. Nature 2015, 524, 155–157. [Google Scholar] [CrossRef] [PubMed] [Green Version]

[3] Summa, D.; Lanzoni, M.; Castaldelli, G.; Fano, E.A.; Tamburini, E. Trends and Opportunities of Bivalve Shells' Waste Valorization in a Prospect of Circular Blue Bioeconomy. Resources 2022, 11, 48. [Google Scholar] [CrossRef]

[4] Tokeshi, M.; Ota, N.; Kawai, T. A Comparative Study of Morphometry in Shell-bearing Molluscs. J. Zool. 2000, 251, 31–38. [Google Scholar] [CrossRef]

[5] Morris, J.P.; Backeljau, T.; Chapelle, G. Shells from Aquaculture: A Valuable Biomaterial, Not a Nuisance Waste Product. Rev. Aquacult. 2019, 11, 42–57. [Google Scholar] [CrossRef] [Green Version]

[6] Vélez-Henao, J.A.; Weinland, F.; Reintjes, N. Life Cycle Assessment of Aquaculture Bivalve Shellfish Production—A Critical Review of Methodological Trends. Int. J. Life Cycle Assess. 2021, 26, 1943–1958. [Google Scholar] [CrossRef]

[7] Zhan, J.; Lu, J.; Wang, D. Review of Shell Waste Reutilization to Promote Sustainable Shellfish Aquaculture. Rev. Aquacult. 2022, 14, 477–488. [Google Scholar] [CrossRef]

[8] Esther O Babatunde, Joshua O Ighalo, Sunday A Akolo, Adewale George Adeniyi, etal (2020) Investigation of Biomedical Characteristics of chitosan produced from crab shells research square

[9] Hiramatsu, H., Kyono, K., Higashiyama, Y., Fukushima, C., Shima, H., Sugiyama, S., ... & Shimizu, R. (2003). The structure and function of human dipeptidyl peptidase IV, possessing a unique eight-bladed β-propeller fold. Biochemical and biophysical research communications, 302(4), 849-854.

[10] Mohanraj, K., Karthikeyan, B. S., Vivek-Ananth, R. P., Chand, R. P., Aparna, S. R., Mangalapandi, P., & Samal, A. (2018). IMPPAT: a curated database of Indian medicinal plants, phytochemistry and therapeutics. Scientific reports, 8(1), 1-17.

[11] Kim, S., Chen, J., Cheng, T., Gindulyte, A., He, J., He, S., ... & Bolton, E. E. (2019). PubChem 2019 update: improved access to chemical data. Nucleic acids research, 47(D1), D1102-D1109.

[12] Daina, A., Michielin, O., & Zoete, V. (2017). SwissADME: a free web tool to evaluate pharmacokinetics, drug-likeness and medicinal chemistry friendliness of small molecules. Scientific reports, 7(1), 1-13.

[13]. Gfeller, D., Grosdidier, A., Wirth, M., Daina, A., Michielin, O., & Zoete, V. (2014). SwissTargetPrediction: a web server for target prediction of bioactive small molecules. Nucleic acids research, 42(W1), W32-W38.

[14]. Molinspiration, C. (2011). Calculation of molecular properties and bioactivity score. http://www. molinspiration. com/cgi-bin/properties.

[15] Banerjee, P., Eckert, A. O., Schrey, A. K., & Preissner, R. (2018). ProTox-II: a webserver for the prediction of toxicity of chemicals. Nucleic acids research, 46(W1), W257-W263.

[16] Morrison, J. L., Breitling, R., Higham, D. J. and Gilbert, D. R. (2006) A lock-and-key model for protein-protein interactions. Bioinformatics, 22, 2012–2019Morrison, J. L., Breitling, R., Higham, D. J. and Gilbert, D. R. (2006) A lock-and-key model for protein-protein interactions. Bioinformatics, 22, 2012–2019.

Sustainable Production of Nickel Cobalt Sulfide nanocomposite for Energy Storage Purposes

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Abstract

Sustainable production refers to the process that reduces the usage of harmful chemicals that deteriorate the environment and focuses on promoting eco-friendly methods to synthesize products, leaving behind resources for future generations. Transition metal chalcogenides have always played a vital role in enhancing the storage and conversion properties of electrodes. However, the harmful chemicals that have been previously used for the reduction of metals pose a serious threat to the environment, which in turn is being replaced by eco-friendly or green reducing agents that are of low environmental impact and cost effective. Herein, we have reported the synthesis of plant extract (*clerodendrum paniculatum*) via simple immersion method which mediated the one-pot synthesis of nickel cobalt sulfide nanocomposite by simple method. The plant extract exhibited phenomenal anti-fungal and anti-bacterial properties making it suitable for a good reducing agent. The as-synthesized nano composites were characterized by UV-VIS spectroscopy showing an absorbance peak at 220nm exhibiting the presence of chromophores facilitating the redox reaction, Fourier Transform Infrared Spectroscopy (FTIR) exhibiting the various functional groups present like alkenes, carboxylic acids, amines etc., and X-ray diffraction (XRD) to predict the amorphous nature of the nanocomposites. The energy storage properties were investigated by electrochemical studies such as cyclic voltammetry revealing the pseudo-capacitance nature of the nickel cobalt sulfide nanocomposite and electrochemical impedance spectroscopy which showcased the enhanced electrocatalytic property of the binary metal counterparts synthesized via green method.

Keywords: green method, immersion, plant extract, transition metal chalcogenides.

1. Introduction

The need for the commercial application of nanomaterials is expanding across various fields such as modern technology, medicine, environment, and agriculture[1]. Energy-intensive procedures are frequently used in nano synthesis. By investigating energy efficient techniques,lowering overall energy consumption and promoting the sustainability of nanomaterials manufacturing, green chemistry rises to the occasion[2]. Green chemistry promotes methods that reduce waste, maximize resource efficiency, and make use of renewable resources[3]. Biocompatible nanoparticles are created using a green synthesis approach that utilizes naturally occurring substances for their quick development, low cost of culture, and ease of control and manipulation of the growing environment[4]. Transition metal chalcogenides are excellent materials that can be used for energy storage purposes. Their remarkable features include substantial surface area, providing abundant active sites for electrochemical reactions and facilitating efficient charge transfer kinetics, a good chemical stability in electrochemical settings, ensuring extended device durability and cycle life and active participation in redox reactions during charge/discharge cycles enhancing specific capacitance and augments energy

storage capacities, particularly in supercapacitors and batteries[5]. Nickel (Ni) materials are highly esteemed in the domain of supercapacitors owing to their exceptional electrochemical characteristics, which encompass prolonged cycle life, rapid charge/discharge rates, and high specific capacity. They find extensive utility in energy storage systems, hybrid vehicles, portable electronics, and renewable energy installations. Ni-based materials can be amalgamated with other substances to create composites or hybrid electrodes. This adaptability empowers researchers to innovate and refine supercapacitor electrode designs. Incorporating Ni materials with carbon nanomaterials in supercapacitors enhances overall performance by boosting conductivity, enlarging surface area, improving stability, facilitating ion diffusion, and capitalizing on synergistic interactions between the materials[6]. In a nutshell, this article provides an insight of the simple one-pot synthesis of eco-friendly nanocomposites and its utilization for energy storage applications.

2. Materials and Methods

2.1 Preparation of plant extract

The Indian plant leaves of *clerodendrum paniculatum* were selected from Kerala on the basis of cost effectiveness and ease of availability. Fresh and healthy leaves were collected and rinsed thoroughly first with tap water followed by distilled water to remove all the dust and unwanted visible particles, cut into small pieces and dried at room temperature. About 10 g of these finely incised leaves of each plant type were weighed separately and transferred into 400 ml beaker containing 100 mL ethanol and kept in magnetic stirrer for 1 hour. The extracts were then filtered twice through Whatman No. 1 filter paper to remove particulate matter and transferred to 250 ml standard flask.

Figure 1: Stages of drying of the plant

2.2 Phytochemical Screening

Test for Flavonoids:

To 2 ml of plant extract taken in a test tube, 10% NaOH solution added and observedfor formation of yellowish-brown colourindicates presence of Flavonoids.

Test for Saponins:

To 10 ml of plant extract mixed with ml water, shake well and observed for formation of form, which lasts for a long time.

Test for Tannins:

1 ml of extract treated with 10% lead acetate solution and observed for formation ofwhite precipitate.

Test for Phenols:

A little amount of extract is treated with 3 to 4 drops of ferric chloride solution and observed for formation of bluish black colour.

Test for Glycosides:

To a little amount extract mixed with water, NaOH solution is added and observed for formation of yellow colour.

Test for Terpenoids:

To a little amount of extract, few dops of chloroform and concentrated sulphuric acid are added. And it is observed for formation of reddish-brown colour.

Test for Alkaloid:

To the extract, 2 ml of Wagner's reagent (2.5g of Iodine in 12.5g of potassium iodide) was added, observed for the formationof reddish-brown precipitate.

Test for Coumarins:

To 1 ml extract, 1 ml of sodium hydroxide was added. Observed for the appearance of yellow colour.

Test for Quinones:

To 1ml extract, 1 ml of dilute NaOH was added and observed for the formation of red colour.

2.3 Synthesis of Nanocomposite

Nickel Carbonate ($NiCO_3$), Cobalt Nitrate ($Co(NO_3)_2$) and Thiourea (CH_4N_2S) were taken in a 250 ml Round Bottom flask in 1:1:2 ratio. 10 ml plant extract was added to the Round Bottom flask and dissolved in 90 ml water. The solution was kept in a magnetic stirrer for 1 hour. The reaction mixture was transferred to an oil bath and heated for 3 hours at 200 °C. The change in colour of the solution confirms the formation of nano composite. The obtained precipitate was then centrifuged at 1500 rpm for 20 minutes. The precipitate was dried using hot air oven at 80°C for 2 hours and kept in tight bottles for further studies.

3. Results and Discussion

3.1 Phytochemical Screening

The preliminary phytochemical screening of *clerodendrum paniculatum* ethanolic extract showed the presence of the following constituents.

It is summarized in the table below

Table 1 Phytochemical constituents

Phytochemical Constituents	***Clerodendrum Paniculatum* ethanolic extract**
Alkaloids	+
Coumarins	-
Terpenoids	+
Tannins	+
Saponins	+
Steroids	+
Flavonoids	+
Anthocyanins	-
Phenol	+
Quinones	-
Glycosides	+
Saponins	+

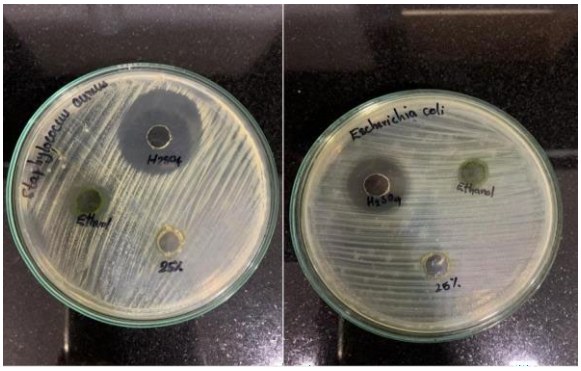

Figure 2 Inhibition of plant extract against *staphylococcus aureus* and *Ecoli*

3.2 Anti-bacterial activity of plant extract:

Table 2 Antibacterial activity of ethanolic plant extract

Sl. No	**Plant extracts**	**Radius zone of inhibition(mm)**	
		E. coli	*Staphylococcus aureus*
1	*Plant extract*	12mm	14mm

The ethanol extract of *clerodendrum paniculatum* showed 12mm against *E.coli* and 14 mm of inhibition against *Staphylococcus aureus*. Therefore, the plant extract of *clerodendrum paniculatum* has good anti-bacterial property and can be used for further studies.

3.3 Anti-oxidant activity of plant extract:

Table 3 Anti-oxidant activity of plant extract

Sample Concentration	**OD Value at 540nm**
Ethanol extract (100µl)	0.85
Samples	**Antioxidant Value**
Ethanol extract (100µl)	420 µl

The antioxidant activity of the ethanolic extract of *clerodendrum paniculatum* showed an optical density of 0.85 corresponding to 100 µl of the sample.

Considering the good anti-oxidant property of the *clerodendrum paniculatum* plant extract, it can be further used in cancer research studies.

3.4 XRD analysis:

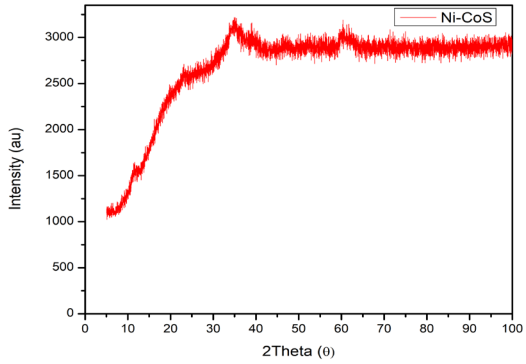

Fig 3 XRD pattern of Ni-CoS

XRD patterns of synthesized nickel cobalt sulfide nano particles using Clerodendrum paniculatum extract shown in figure. It shows scattered and suppressed peaks which indicates that the nano composite synthesized by green synthesis method could be amorphous[7]. Similar reports were reported in previous papers [8,9]. In the XRD pattern, there is a slightly broadened peak between 30-40º. This signifies that there has been formation of nickel sulfide which has been intervened by the cobalt particles. This confirms that the nanocomposite has been formed. The broadness of the peak indicates the amorphous nature of material.

3.5 FT-IR Analysis

In FT-IR spectra, the nano composites product prepared by using Clerodendrum Paniculatum plant as the reducing agent showed the functional groups like alkane, alkene, haloalkanes, carboxylic acids and amine etc.

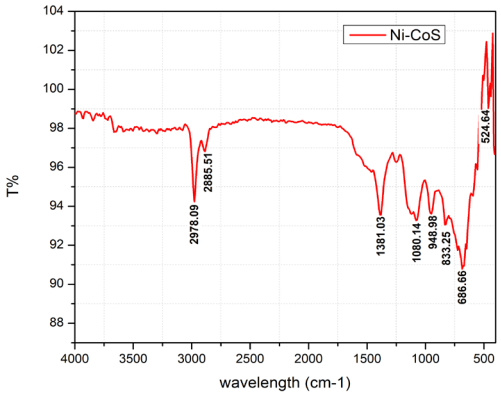

Figure 4 FT-IR Spectra of Ni-CoS

FT-IR showed peaks at 2978.09 cm^{-1}, 2885.51 cm^{-1}, 1381.03 cm^{-1}, 1080 cm^{-1}, 948.98 cm^{-1}, 832.25 cm^{-1}, 686.66 cm^{-1}, 524.64 cm^{-1},462.92 cm^{-1}, and 439.77 cm^{-1}. The peak valuesat 2978.09 cm^{-1} and 2885.51 cm^{-1} correspondto the C-H bonds in alkyl groups. The band at 1381.03 cm^{-1} corresponds to the presence of C-O bond. In the previous studies, peak at 686.6 cm^{-1} were attributed to the vibrations of Ni-S in the nickel sulfide phases. The bands atthe ranges of 1080.14 cm^{-1} and 686.66 cm^{-1} were attributed to the C-S bond from the precursor[10]. 2978.09 cm^{-1} and 2885.51 cm^{-1} corresponded to N-H bonds in free amines. The band at 832.25 cm^{-1} indicates the characteristic band of sulfides[11]. According to Sohrabnezhad et al., peak at the range of 1080 cm^{-1} confirms the existence of Co-S bond in the composite[9]. From the FTIR pattern, formation of Ni-Co-S nano compositeis confirmed.

3.6 UV-Vis Spectroscopy:

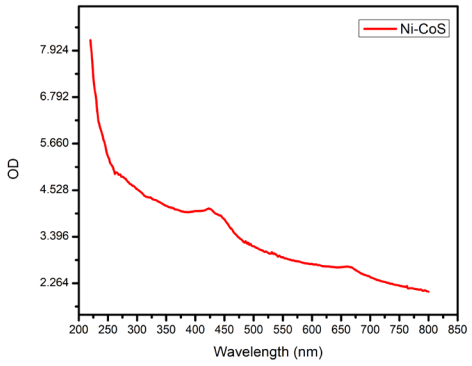

Figure 5 UV-VIS Spectra of Ni-CoS

The transmission spectrum of the synthesizedproduct recorded in UV region is shown in theFig shows that the synthesized nanocomposite have high absorption in the UV region at 220nm, than in any other region of spectrum. According to the previous reports, Cobalt Sulfide shown to have absorption peak in a range of 350 nm[203]. Nickel sulfide shown to have peaks in the range of 223 nm-360 nm[10, 11]. Hence, formation of Ni-Co-S nano composite can be confirmed from the UV-VIS spectroscopy study. The result obtained for the synthesized composite were slightly lesser than those reported in previous reports, which can be attributed to the strong dependence of optical band gap on the amorphous nature of the composite.

3.7 Cyclic Voltammetry:

Pseudocapacitive performance of the nickel cobalt sulfide nano particles has been researched in a three-electrode system. Figure 6 depicts the representative CV curves of nickel cobalt sulfide modified Ni foam electrode at different sweeping rates within the potential range 0 to 0.6 V .

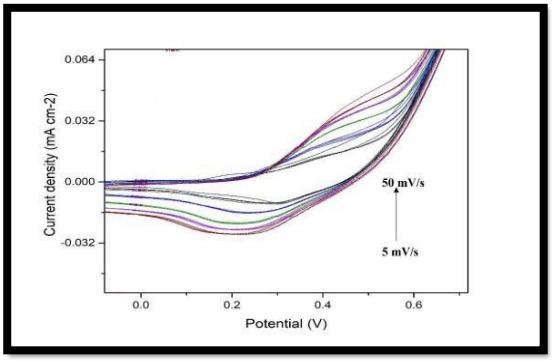

Figure 6 Cyclic voltammograms of Ni-CoS

We can observe a pair of redox peaks over the entire sweep range. According to the previous report [7], it is evident that the nickel cobalt sulfide nanomaterial exhibit pseudocapacitive characteristics. CV properties of nickel cobalt sulfide modified Nifoam electrode are consistent with the previous reports. From the CV curve it is evident that both the oxidation and reduction peak positions have been shifted to both sides as scan rate increased. According to Cheng etal., this may be caused by the limitation of the OH- ion diffusion rate in the redox process to satisfy electronic neutralization[7]. According to previous reports, the broad redox reaction peaks which come from the redox processes of $Co^{2+}/Co^{3+}/Co^{4+}$ and Ni^{2+}/Ni^{3+} are characteristic of electrochemical pseudo capacitors from reversible faradaic redox reactions occurring within the electroactivematerials[12, 13].

$$CoS + OH^- \leftrightarrow CoSOH + e^-(1)$$

$$NiS + OH^- \leftrightarrow NiSOH + e^-(2)$$

Two redox couples, CoS/CoSOH and NiS/NiSOH, are generally involved in the reaction system. According to previous studies, CV patterns of same sample can be different due to their difference in morphology, difference in the synthesis method, and surface properties of prepared electrodes. The CV properties of the synthesised Ni-Cd-S are consistent with the previous reports, which further proves that both the redox reactions shown in equations (1) and (2) are existing in the charge storage mechanism.

3.8 Electrochemical Impedance Spectroscopy

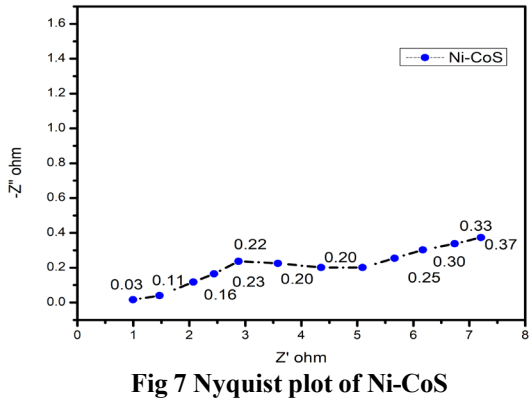

Fig 7 Nyquist plot of Ni-CoS

In the result shown in figure 7, it is evident that Nickel Cobalt Sulfide nanocomposite has better charge transfer ability. The excellent electrochemical performance of Nickel Cobalt Sulfide benefit from the fact that, the highly

conductive nickel-cobalt sulfide contact directly on the conductive Ni foam to form an integrated electrode with super highways for fast electron transportation and electrolyte ion diffusion, which greatly increase the charge rate of electrode for high power applications[14]. The study describes the green synthesis of Nickel and Cobalt based nanocomposite has better energy storage applications. It exhibits better electro catalytic performance than that of binary counterparts. The enhanced catalytic performance is achieved by the green synthesis method[15].

4. Conclusion

In this study, nickel cobalt sulfide nano composite was prepared. The synthesis was carried out by a simple one-pot method with the plant extract of *clerodendrum paniculatum* was used as the reducing agent. Plant extracts were tested for phytochemical analysis, anti-microbial activity and anti-oxidant activity. Ethanolic plant extract were shown to have better antimicrobial and anti-oxidant activity. The synthesized nanocomposite was characterized by UV-VIS spectroscopy, Fourier Transform Infrared Spectroscopy (FTIR), X-ray diffraction (XRD). From the UV-VIS spectroscopy, FTIR analysis and XRD analysis, size of the synthesized nano composite, functional groups present in the nano composite and amorphous nature of nano composite were detected. For the study of application of synthesized nanocomposite, Cyclic Voltammetry and Electrochemical Impedance Spectroscopy were used. The amorphous structure can enhance the utilization of the electroactive nickel cobalt sulfide for the faradic redox reactions. These results show that the simplegreen synthesis method adopted in the present study can be readily extended toprepare other amorphous nano materials forsupercapacitors.

5. References:

[1] Dhinakaran Veeman, M. Varsha Shree, P. Sureshkumar,T. Jagadeesha, L. Natrayan,M. Ravichandran , and Prabhu Paramasivam (2021) Sustainable Development of Carbon Nanocomposites: Synthesis and Classification for Environmental Remediation, Journal ofNanomaterials, 2021 (1), 1-21.

[2] Anastas, P. T., and Beach, E. S. (2007). Green chemistry: the emergence of a transformative framework. Green Chemistry Letters and Reviews, 1(1), 9-24.

[3] Clark, J. H. (2001). Catalysis for green chemistry. Pure and Applied Chemistry 73(1), 103-111.

[4] Iravani, S. (2011). Green synthesis of metal nanoparticles using plants. Green Chemistry, 13(10), 2638-2650.

[5] Swagatika Kamila ,Manikandan Kandasamy, Brahmananda Chakraborty, Bikashkumar Jena, (2024), Recent development onengineered TMDs for charge storage performance: Experimental and theoreticalinvestigations**,** 89, 111614.

[6] Ghobad Behzadi Pour, Hamed Nazarpour Fard, Leila Fekri Aval and Deepak Dubal (2023), Mater Adv. 4, 6152-6174.

[7] Tie, J., Han, J., Diao, G., Liu, J., Xie, Z., Cheng, G., & Yu, L. (2018). Controllable synthesis of hierarchical nickel cobalt sulfide with enhanced electrochemical activity. Applied SurfaceScience, 435, 187-194.

[8] Ramachandran, R., Felix, S., Saranya, M., Santhosh, C., Velmurugan, V., Ragupathy, B.P. C., & Grace, A. N. (2013). Synthesis of cobaltsulfide–graphene(CoS/G) nanocomposites for supercapacitor applications. IEEE transactions on nanotechnology, 12(6), 985-990.

[9] Iqbal, J., Abbasi, B. A., Mahmood, T.,Hameed, S., Munir, A., & Kanwal, S. (2019).Green synthesis and characterizations of Nickel oxide nanoparticles using leaf extract of Rhamnus virgata and their potential biological applications.Applied Organometallic Chemistry, 33(8), e4950.

[10] Karthikeyan.R., Thangaraju, D.,Prakash, N., & Hayakawa, Y. (2015). Single- step synthesis and catalytic activity of structure- controlled nickel sulfide nanoparticles. CrystEngComm, 17(29), 5431-5439.

[11] S. Peng, L. Li, C. Li, H. Tan, R. Cai, H. Yu, S. Mhaisalkar, M. Srinivasan, S. Ramakrishna, Q. Yan, (2013), In situ growth of NiCo2S4nanosheets on graphene for high- performance supercapacitors. Chem.Commun. 49, 10178.

[12] H. Wan, J. Jiang, J. Yu, K. Xu, L. Miao,L. Zhang, H. Chen, Y. Ruan, (2013) $NiCo_2S_4$ porous nanotubes synthesis via sacrificial templates: high-performance electrode materials of supercapacitors. Cryst Eng Comm 15, 7649

[13] H. Wang, L. Zhang, X. Tan, C.M. Holt, B. Zahiri, B.C. Olsen, D. Mitlin, (2011) Super capacitive properties of hydrothermally synthesized Co3O4 nanostructures. J. Phys. Chem. C 115, 17599.

[14] Gowrisankar, A., Sherryn, A. L., & Selvaraju, T. (2021). In situ integrated 2D reduced graphene oxide nanosheets with MoSSe for hydrogen evolution reaction and supercapacitor application. Applied Surface Science Advances, 3, 100054.

[15] Zahariev, I., Piskin, M., Karaduman, E., Ivanova, D., Markova, I., & Fachikov, L. (2017). FTIR Spectroscopy Method for Investigation of Co-Ni Nanoparticle Nanosurface Phenomena. Journal of Chemical Technology & Metallurgy, 52(5).

GREEN SYNTHESIS OF NITROGEN-DOPED CARBON QUANTUM DOTS USING CORNCOB WASTE FOR SMART PLANT SENSOR

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Abstract

Lead detection appears to be a crucial undertaking due to its serious toxicity. Lead is non-degradable in the environment, resulting in persistent contamination over time. It can accumulate in plants and animals, becoming part of the food chain and potentially impacting a diverse array of organisms, including humans who consume contaminated food. Herein, a new smart plant sensor based on nitrogen-functionalized carbon quantum dots (N-CQDs) with an average size of 2.6±0.5 nm was synthesized from corncob, a globally abundant agricultural byproduct, and green-doped using soybeans through a one-step microwave-assisted pyrolysis method. The N-CQDs exhibited low cytotoxicity and demonstrated high sensitivity and selectivity in fluorescence response toward Pb^{2+}. These N-CQDs do not have any noticeable impact on the growth of mung bean plants, in which case 0.4 mg/mL can enhance the growth of mung bean plants in root length and dry weight. In addition, even at the highest concentration (3.2 mg/mL), there is no indication of notable toxicity. Further studies demonstrated that the sensing platform, which was constructed using N-CQDs coordinated with plants, can visually observe and detect Pb^{2+}. This study presents an innovative green doping synthesis method and Pb2+ sensing platform within plant organisms using carbon quantum dots, which could pave the way for a future approach for simple smart plant-based sensors that could detect environmental contaminants and monitor plant health spatially and temporally.

Keywords: Carbon quantum dot, Nitrogen doped carbon quantum dots, Green Synthesis, Green Doping, Lead ion, Fluorescent sensor, Smart plant sensor

1. Introduction

Agricultural waste has emerged as an intriguing source for green synthesis of nanomaterials, including nanocellulose, silicon nanoparticles (SiNPs), metal oxide nanoparticles (MONPs), and carbon nanomaterials. It was successfully employed as a predecessor to nanomaterials. It is estimated that up to one-third of the global food supply is lost or wasted each year [1], resulting in significant environmental consequences such as the greenhouse effect and PM2.5 [2]. As a result, converting agricultural waste into usable materials such as nanomaterials is an example of sustainable management. SiNPs, for example, were synthesized using rice husk [3-5], sugar cane [6], and coconut husk [7], whereas carbon materials were produced using bamboo [8], lignin [9], orange peels [10, 11], watermelon peels [12], and lychee seeds [13, 14].

Carbon quantum dots (CQDs), a nanoscale carbon-based material, exhibit unique optical properties and are gaining prevalence in a variety of applications. Their unique features include high quantum yield, minimal toxicity, biocompatibility, configurable fluorescence, photostability, and water solubility [15, 16]. Their diameter is typically less than 10 nm, and they are formed of sp2 or sp3 -hybridized carbon atoms arranged in a graphitic structure with surface functional groups such as hydroxyl, carboxyl, and amine groups. The surface modification alters several characteristics, resulting in unique optical characteristics and possible applications [17-25]. Nitrogen-doped CQDs, for example, can improve sensitivity and selectivity for

simultaneous detection of Pb^{2+} [18] CQDs doped with nitrogen have a high quantum yield and effective to be used as a fluorescent sensor for the detection of metal ion with high selectivity[21-24]. Furthermore, nitrogen-doped CQDs are less cytotoxic and have higher biocompatibility than undoped CQDs [25]. In addition to doping, the characteristics of CQDs are affected by the precursors and synthesis method used. The synthesis of CQDs is becoming increasingly popular. They can be synthesized via a variety of approaches, such as thermal decomposition [26], electrochemical oxidation, and chemical functionalization [27]. Nonetheless, these synthesis methods can produce toxic pollutants, and they are also expensive and time-consuming [28]. Because of its cost efficiency and shortening of the process time, microwave-assisted pyrolysis is a promising process for the efficient and sustainable production of various products from organic materials. Due to environmental concerns, there has been a rapid increase in the number of sustainable and eco-friendly methods for synthesizing nanomaterials. As a result of using agricultural waste as a source of surface modification agents, refuse materials can be recycled and transformed into a product with added value. Agricultural waste, such as raisins and soy beans, is rich in naturally occurring nitrogen [32], which can be used as surface modification material for CQDs. CQDs have the potential to be an effective plant-based sensor for monitoring plant environmental and growth factors in real time. This promotes precision agriculture and lessens agricultural loss due to stress, deficiency, or excess of a significant factor [33, 34]. The tunable fluorescence emission wavelength and intensity of CQDs after interaction with a target molecule [16] can indicate the presence and concentration of target molecules. CQDs are thus an effective fluorescence sensor probe. They have been used as optical sensors for a wide range of targets, including heavy ions, biomarkers, biomolecules, and target sites, with high sensitivity and selectivity and a low detection limit [34-37]. CQDs have demonstrated great promise as optical nanosensors in biosystems. As a result, a number of outstanding articles on CQD-based sensors [14, 16, 23-25, 28, 34, 36-46] and green CQD synthesis [8, 14, 24-26, 36-38, 44, 47] have been widely studied. However, the green synthesis of CQDs with green doping using non-chemical precursors such as the elements found in foods and fruits [32] has been rarely reported.

In light of this, we are primarily interested in developing synthesis techniques for CQDs using green precursors and dopers derived from agricultural waste (corncob and soy bean). We intend to demonstrate the alternative potential of these CQDs for use in smart plant nanosensors. The main objective is on the green synthesis of CQDs doped with nitrogen derived from plants. This will be compared to CQDs synthesized using other approaches. The green synthesis in this work is based on the use of microwave-assisted pyrolysis to make it more environmentally friendly, sustainable, and energy efficient. CQDs will also be investigated for use as a smart plant sensor and in imaging applications. Our developed synthesis approach has the potential to be used in a variety of biomedical applications, including bioimaging biosensors and ion-sensors, and can be adapted to produce a precision agriculture monitoring probe.

2. Experimental Section

2.1 Materials and Chemicals.

Corncob waste (Thailand). Copper (II) nitrate trihydrate ($Cu(NO_3)_2 \cdot 3H_2O$) was purchased from QReC (New Zealand). Iron (II) chloride tetrahydrate ($FeCl_2 \cdot 4H_2O$) was purchased from EMSURE (Germany). Lead (II) chloride ($PbCl_2$) was purchased from Aldrich Chemistry (United Kingdom). Cobalt (II) chloride ($CoCl_2 \cdot 6H_2O$) was purchased from Ajax Finechem (Australia). Mercury (II) chloride ($HgCl_2$) was purchased from QReC (New Zealand). Magnesium (II) Chloride Hexahydrate ($MgCl_2 \cdot 6H_2O$) was purchased

from RCI Labscan (Bangkok). Deionized Water Ethanol Absolute (AR1069) was purchased from RCI Labscan (Bangkok). Tween 20 Extra pure was purchased from Loba Chemie (India). Haiter Bleach was purchased from Kao Industrial (Bangkok).

2.2 Instrumentation and Characterization.
Microwave oven (SHARP, R-9320G-BS) was performed. The structural information on the prepared CQDs including conformation, shape, and average size was investigated by transmission electron microscope (TEM) (FEI, TECNAI G2 20). Fourier transform infrared (FT-IR) (Bruker, TENSOR27) spectra in the range of 4000−500 cm^{-1} were recorded to determine the functionalized group, bonding in CQDs. Sample excitation wavelength, emission wavelength, and fluorescence sensing were detected on a UV-Vis spectrophotometer (Hitachi Japan, S-3000N) and fluorescence microplate reader (Molecular devices, SpectraMax M5).

2.3 Preparation of CQDs
Preparation of Carbon Quantum Dots from Corncob (CC-CQDs).
20g of Corncob crudes were mixed in a Duran with 10 mL of deionized water, and then the mixture was stirred vigorously for 1 minute on a magnetic stirrer. After that, the Duran was transferred into a microwave oven and performed at 1200 watts for 7 minutes. After allowing the mixture to reach room temperature for 24 hours, the product was re-dissolved in deionized water, then purified. The purified CC-CQDs solution was freeze-dry for 48 hours. Finally, the CC-CQDs were collected as a dark-brown crude and stored at -20°C.

Preparation of Nitrogen-doped Carbon Quantum Dots from Soybean (N-CQDs).
Corncob crudes and Soybean crudes were mixed in the ratios of 1:1 (10g:10g) in a Duran with 10 mL of deionized water, and then the mixture was stirred vigorously for 1 minute on a magnetic stirrer. After that, the Duran was transferred into a microwave oven and performed at 1200 watts for 7 minutes. After allowing the mixture to reach room temperature for 24 hours, the product was re-dissolved in deionized water, then purified. The purified CC-CQDs solution was freeze-dry for 48 hours. Finally, the CC-CQDs were collected as a dark-brown crude and stored at -20°C.

Synthesis of CC-CQDs and N-CQDs.
CQDs were prepared by a simple microwave-assisted pyrolysis method. Firstly, 100, 300, 500, 700, 1000, 10,000, and 20,000 mg of corncob crude were mixed in a Duran with 10 mL of deionized water, and then the mixture was stirred vigorously for 1 minute on a magnetic stirrer. The Durans were transferred into a microwave oven and performed at 1200 watts. The duration of the microwave pyrolysis varied from 1, 3, 5, 7, 9, and 12 minutes. After allowing the mixture to reach room temperature for 24 hours, the product was re-dissolved in deionized water, then sonicated for two hours and centrifuged at 10,000 rpm for ten minutes. The product solution was filtered by filter paper, followed by Nylon syringe filters, respectively. Next, the CC-CQDs solution was purified using a Spectra/Por dialysis membrane with molecular weight cutoffs of 100–500 Daltons in deionized water for 72 hours. The purified CQDs solution was put into freezer-dryer machinery for 48 hours. Finally, the CQDs were collected as a dark-brown crude and stored at -20°C.

2.4 Cytotoxicity and cell growth.
Mung bean seeds were selected for their uniform size and heft. Submerge bean seeds in a beaker of 70% ethanol solution (100 seeds per beaker) while simultaneously agitating with a magnetic bar for 2 minutes. Remove any floating seeds and rinse off the ethanol. Next immerse the seeds in a solution composed of 10 mL of hydrogen peroxide and ethoxylated alcohol solution, 1 mL of Tween Twenty, and 90 mL of deionized water, and

then agitate the mixture vigorously for 20 minutes. Rinse the solution and transfer the seeds into 100 mL beaker filled with deionized water, then agitated for 10 minutes. Repeat the washing process four more times. Set up petri-dishes and prepare a solution containing carbon quantum dots (CQDs) of varying concentrations (200, 400, 800, 1600, and 3200 µg/mL). Distribute the seeds evenly, placing 10 seeds in each dish. Store the petri-dishes in a black room and regularly monitor seed germination progress on a daily basis. After 6 days, the bean sprouts were immediately weighed for their wet weight, dried in an oven at 85°C for 7 days, and then weighed for their dry weight. Comparing the sprouts' post-drying weight to their starting weight to determine moisture content.

2.5 Fluorescence Sensing Experiments.

The incubation time of the N-CQDs fluorescence sensor with Pb^{2+} were measured at different response times ranging from 0 to 45 minutes (measured every 5 minutes). The fluorescence intensity at a specific wavelength (450 nm) was measured in the presence of various concentrations of Pb^{2+} (0–240 µM). The calibration curve for ion sensing was provided to ensure accurate measurements. Next, the fluorescence response of N-CQDs towards various metal cations was investigated. N-CQDs were dispersed in deionized water to a concentration of 3200 µg/mL and then the metal ions (Pb^{2+}, Hg^{2+}, Mg^{2+}, Fe^{2+}, Co^{2+}, and Cu^{2+}) introduced into the aqueous solution to the final concentration of 240 µM at room temperature. Fluorescence measurements were taken to assess the response of N-CQDs to each metal ion.

2.6 Detection of Pb^{2+} in Tap Water Samples.

Additionally, tap water samples were obtained from the Department of Physics at Khon Kaen University (KKU), and spiked with various concentrations of Pb^{2+} ions and then performing fluorescence detection.

2.7 Feasible use of N-CQDs plants sensor to detect Pb^{2+} .

White onions were used to investigate the realtime sensing of Pb^{2+} ions using plants with CQDs (a plant-based nanosensor). The white onions were incubated with N-CQDs for 30 min before being transferred to a new petridish and incubated with Pb^{2+} ions for 20 minutes, and being washed three times with deionized water. In comparison to the control experiment, fluorescence quenching were observed using a high-definition mobile phone as the image acquisition tool and a computer's built-in algorithm program as the processing tool for correcting the RGB color value.

3. Results and Discussion

3.1 Characterization of CC-CQDs and N-CQDs.

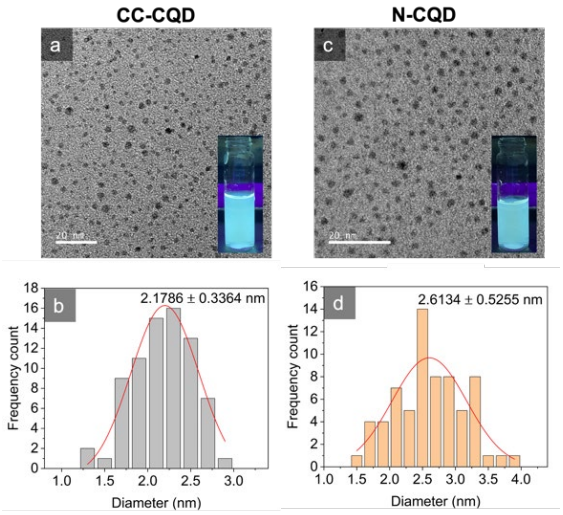

Fig. 1 TEM image of (a) CC-CQDs and (c) NCQDs, size distribution of (b) CC-CQDs, and (d) NCQDs.

Corncob-carbon quantum dots (CC-CQDs) and nitrogen-doped carbon quantum dots (N-CQDs) display intense photoluminescence as a result of their quantum confinement effect and surface states. The absorption spectra of these dots often exhibit an excitation peak that occurs within the wavelength range of 290–480 nm. TEM images demonstrate that CC-CQDs have a spherical morphology with a particle diameter of around 2.1±0.3 nm, whereas N-CQDs similarly possess a

spherical shape, with a diameter of approximately 2.6±0.35 nm (Figure 1). The FT-IR spectra were shown in Figure 2b reveal distinct absorption bands at 1055 cm^{-1}, 1285 cm^{-1}, and 3260 cm^{-1}, corresponding to the stretching vibrations of C-O, C-N, and N-H groups, respectively. These features demonstrate the presence of active surface groups . The FT-IR spectrum of N-CQDs and CC-CQDs exhibited a prominent absorption peak at 1630, suggesting the stretching vibrations of C=C/C=N, hence confirming the successful nitrogen-green doping. Furthermore, the fluorescence intensity of N-doped CQDs is notably higher compared to undoped CQDs. This enhancement is attributed to the increased chemical reactivity of surface atoms and molecules in N-CQDs, which reduces non-radiative recombination pathways.

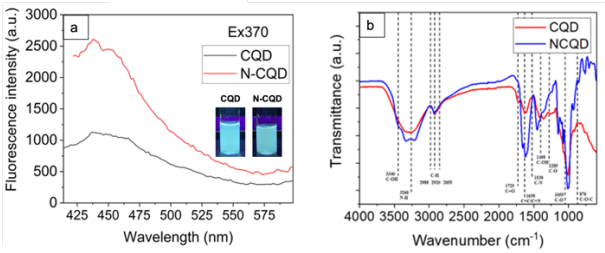

Fig. 2 (a) Fluorescence and (b) FTIR spectra of CC-CQD and N-CQD.

3.3 Growth and development of mung beans

Mung bean sprouts were exposed to N-CQDs at various concentrations (0, 0.2, 0.4, 0.8, 1.6, and 3.2 mg/mL). After six days, the root and stem lengths of the bean sprouts were measured, and their moist weights were recorded. The dry weight of the sprouts was determined after seven days of oven drying at 85°C. The resulting data indicate similar trends across the various growth factors as shown in figure 4. The moisture level in the mung bean sprouts (Figure 4(f)) represents the amount of water lost in relation to the total fresh mass of the sprouts. When mung beans were exposed to various concentrations of N-CQD solution and compared to those treated with deionized water, the moisture content remained virtually the same (92-94%). This indicates that N-CQDs have no phytotoxicity on mung bean growth.

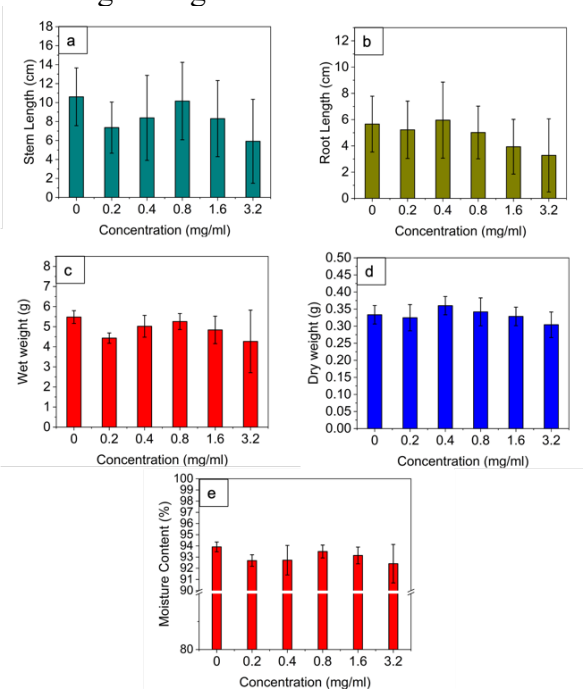

Fig. 3 Effects of N-CQDs on the growth and development of mung beans (a) stem length, (b) root length, (c) wet weight, (d) dry weight (f) moisture content (%)

Table 1 Effect of N-CQDs on growth of bean. (* sig. $p < 0.05$)

ANOVA		Multiple Comparisons : DI compared to NCQDs3200	
Dependent variable	Between Groups	Post Hoc Tests	
		Tukey HSD	Scheffe
Root Length	-	0.809	0.998
Stem Length	-	1.000	1.000
Dry Weight	0.334	0.815	0.904
Moisture	0.321	0.325	0.507

As presented in Table 1, based on statistical analysis using one-way ANOVA, the dry weight and the moisture content showed no significant decrease in the growth of mung beans, with p-values of 0.334 and 0.321 (higher than 0.05), respectively. And for post-hoc Tukey's test and Scheffe's test, the

lengths of the root and stem presented also show significant toxicity. The analysis provided detailed comparisons that indicated no significant differences between the groups, similar to multiple comparisons . The experimental result showed that even the highest concentrations of nitrogen-doped carbon quantum dots (N-CQDs) (3.2 mg/mL) did not adversely affect the growth of bean sprouts. Therefore, N-CQDs have the potential to be used as smart plant sensors without negatively impacting plant growth or the environment, making them suitable for applications in agricultural monitoring and plant health assessment.

3.4 Sensing of Pb^{2+} Ions.

N-CQDs was utilized as a luminescence probe for the detection of Pb^{2+}. The fluorescence spectra of the detection system at different response times, along with the kinetics curve within 20 minutes, are shown in the figure 3a. As observed, the fluorescence intensity of N-CQDs at 450 nm gradually decreased with increasing response time up to 20 minutes and then stabilized, with no significant decrease beyond 20 minutes.

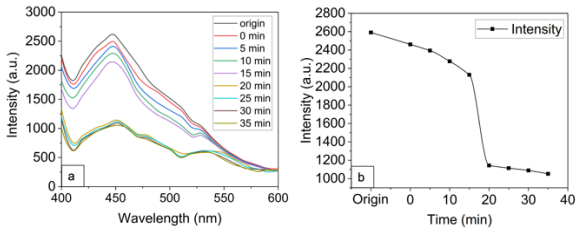

Fig. 4 Optimizing reaction time for Pb^{2+} ion sensing.

This behavior indicates that the reaction between the nanosensor and Pb^{2+} ions occurs quickly, and thus, a 20-minute incubation time was optimized for developing the sensor for Pb^{2+} ion detection. N-CQDs exhibit fluorescence characteristics that change when exposed to Pb^{2+} ions. Increasing the concentration of Pb^{2+} generally leads to a decrease in the fluorescence of N-CQDs. This change is due to the interaction between Pb^{2+} ions and the functional groups on the surface of N-CQDs, which disrupts the fluorescence process. Experimental results show that as the concentration of Pb^{2+} ions increases from 0 to 240 µM, the fluorescence intensity decreases accordingly.

3.5 Performance of the nanosensing

N-CQDs display fluorescence characteristics that undergo alteration when exposed to Pb^{2+} ions. An elevation in Pb^{2+} concentration typically leads to a reduction in the fluorescence of N-CQDs. The alteration is a result of the interaction between Pb^{2+} ions and functional groups on the surface of N-CQDs, which disrupts the fluorescence process. Empirical evidence has demonstrated that in figure 5 the calibration curves of the recently developed nanosensor were generated by adjusting the concentrations of Pb^{2+} ions within the range of 0-240 µM under the most optimal experimental conditions. Figure 5 displays the calibration curves for the Pb^{2+} ion. It is evident that the excitation at 450 nm dropped as the amount of Pb^{2+} ions increased. The absorbance of the N-CQDs solution at a wavelength of 450 nm showed a direct relationship with the concentrations of Pb^{2+} ions in the range of 0-240 µM. The linear regression equation for the ion was found to be $y = -30.9265x + 1326.9$, with a correlation coefficient of 0.9089 for concentrations ranging from 0 to 20 µM (figure 5a). For concentrations ranging from 120 to 240 µM (figure 5b), the equation was $y = -5.0114x + 1286.4$, with a correlation coefficient of 0.873.

3.6 The specificity of the developed nanosensing

N-CQDs are specifically designed to be highly selective towards Pb^{2+} ions compared to other metal ions. This selectivity is due to the unique functional groups on the N-CQDs, which have a strong binding affinity for Pb^{2+}. Adding nitrogen to the carbon quantum dots enhances their electron-donating capabilities, thereby increasing their interaction with Pb^{2+} ions. To evaluate the specificity of the proposed nanosensors, we tested their

response to various metal ions, including Fe^{2+}, Mg^{2+}, Co^{2+}, Cu^{2+}, and Hg^{2+}, under optimal conditions. The results showed that the Pb^{2+} ion exhibited much higher selectivity compared to the other metal ions. This high level of specificity in detecting Pb^{2+} ions was further confirmed by the $(I_0-I)/I_0$ measurements, which demonstrated that the probe maintained its selectivity for Pb^{2+} even in the presence of other interfering ions. This enhanced selectivity is attributed to nitrogen doping, which introduces extra electrons into the material, creating an abundance of negative charges that improve electron donation and interaction with Pb^{2+} ions.

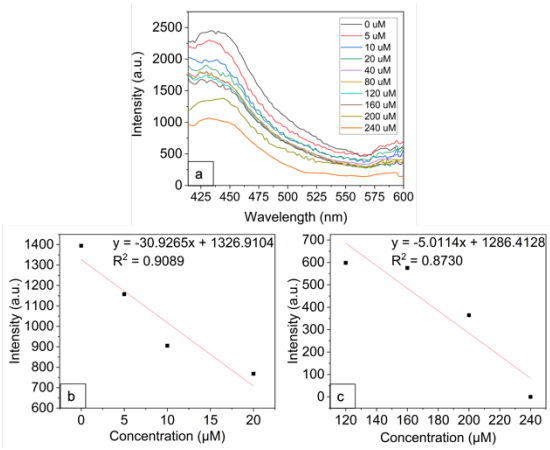

Fig. 5 (a) Intensity spectra of the N-CQDs with different concentrations of Pb^{2+} (0-240 μM) and Calibration curves N-CQDs with concentration 0-20 μM (b) and 120-240 μM (c)

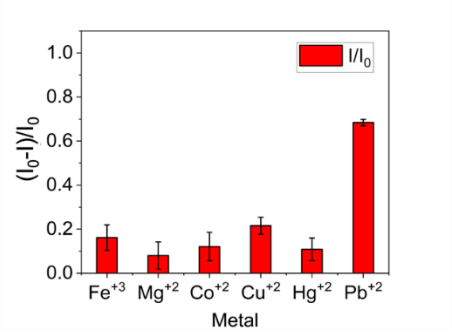

Fig. 6 The specificity of the developed nanosensing

3.7 Detection of Pb^{2+} ions in Tap Water Samples

The analysis revealed the absence of lead ions in the tap water sample. Subsequently, the initial water samples were augmented with varying amounts of the standard, and the sensing procedure was executed. Table 2 displays the data obtained from the experiment. The results shown in Table 2 demonstrate that the nanosensing method successfully produced adequate recoveries (107.2–118.1%) and exhibited good analytical precision. These findings further validate the reliability of the nanosensing technique for monitoring Pb^{2+} ions in water samples.

Table 2 Detection of Pb^{2+} ion in Tap Water Samples

Sample	Added (μM)	Found (μM)	Recovery (%)	RSD (%,n=3)
1	0	-	-	-
2	10	11.81	118.10	4.78
3	180	193.01	107.23	2.89
4	240	249.24	103.85	1.83

3.8 N-CQD as a smart plant sensor

The objective of this experiment is to evaluate the use of smart plant sensors made from carbon quantum dots (CQDs) integrated with white onions and to explore the potential of nitrogen-doped carbon quantum dots (N-CQDs) in smart plant systems as virtual fluorescent sensors. This involves studying the interaction between the N-CQD plant sensor and Pb^{2+} ions using a high-definition mobile phone for image acquisition and a computer's algorithm program for correcting RGB color values. In the experiment, N-CQDs were pretreated with white onion tissue and then immersed in a Pb^{2+} solution (240 μM). When exposed to UV light, the interaction between the CQDs-based smart plant sensors and Pb^{2+} ions resulted in a decrease in fluorescence intensity, a phenomenon known as fluorescence quenching. This behavior, illustrated in Figure 7 and 8, matches the response seen in traditional N-CQDs sensors, indicating that the plant matrix does not interfere with the sensing capability of the N-CQDs. The findings suggest that the CQDs-based smart plant sensor platform can reliably detect Pb^{2+} ions in environmental and biological samples,

performing similarly to traditional CQDs sensor platforms while offering additional benefits such as real-time, in-situ monitoring within plant systems.

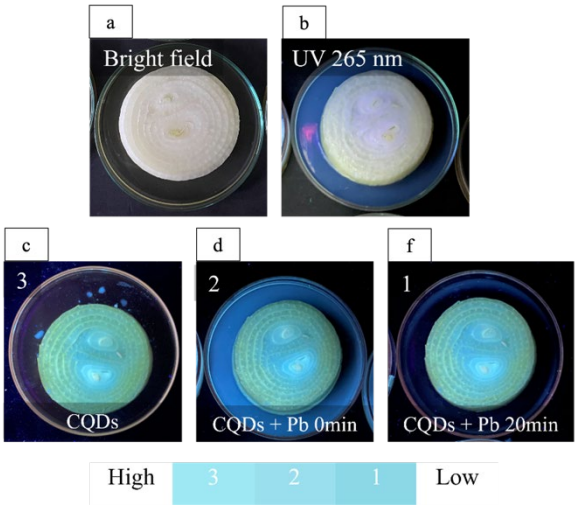

Fig. 7 CQDs-base smart plant sensors platform with the Pb^{2+} (a) bight field, (b) under UV 265 nm, (c) CQDs, (d) CQDs + Pb 0 min and CQDs + Pb 20 min.

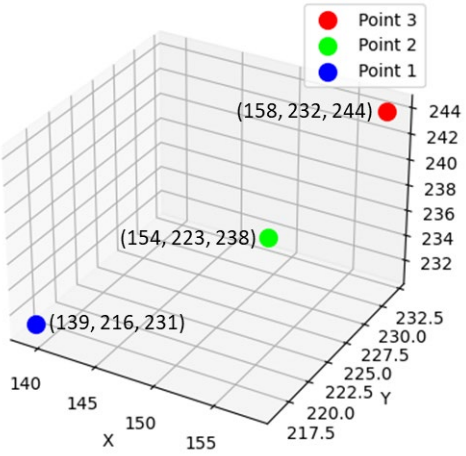

Fig. 8 The RGB color value's point of the CQDs-based smart plant sensor platform.

4. Conclusion

In this study, we developed a nanosensor for detecting Pb^{2+} ions using nitrogen-doped carbon quant μM dots (N-CQDs). These N-CQDs were synthesized through a microwave-assisted pyrolysis method, ensuring efficient and scalable production. Two types of carbon quantum dots were prepared: corncob-derived CQDs (CC-CQDs) and soybean-derived N-CQDs. The N-CQDs exhibited strong fluorescence, which was significantly quenched when exposed to Pb^{2+} ions, providing a sensitive detection method. The N-CQDs showed high selectivity for Pb^{2+} ions over other metal ions. Fluorescence intensity measurements allowed for accurate Pb^{2+} concentration determination, demonstrating the efficacy of N-CQDs as a nanosensor. At a concentration of 300 and a pyrolysis time of 7 minutes, the highest intensity observed was about 5700. The optimal incubation period for detection was 20 minutes. Microwave-assisted pyrolysis was advantageous for synthesizing CQDs and N-CQDs, offering reduced reaction times, improved energy efficiency, and large-scale production. Using biomass sources like corncob and soybean provided a sustainable method and added value to agricultural waste. The CQDs-based smart plant sensor showed consistent fluorescence quenching upon interaction with Pb^{2+} ions, even in a plant matrix, enabling real-time, in-situ monitoring of environmental and biological samples. This innovative approach has potential for developing simple and effective plant-based sensors. In summary, the smart plant sensor shows promise for environmental monitoring and public health protection. Future research will focus on enhancing the sensitivity and selectivity of N-CQDs, testing them in real-world samples, and exploring their ability to detect other heavy metals.

Reference

[1] Capanoglu E, Nemli E, Tomas-Barberan F. Journal of Agricultural and Food Chemistry, 70(23):6787-804, 2022.
[2] Aneja VP, Schlesinger WH, Erisman JW. Environmental Science & Technology, 43(12):4234-40, 2009.
[3] Bose S, Ganayee MA, Mondal B, Baidya A, Chennu S, Mohanty JS, et al. American Chemical Society Sustainable Chemistry & Engineering, 6(5):6203-10, 2018.
[4] Wang W, Martin JC, Fan X, Han A, Luo Z, Sun L. American Chemical Society Applied Materials & Interfaces, 4(2):977-

81, 2012.
[5] Chen H, Wang W, Martin JC, Oliphant AJ, Doerr PA, Xu JF, et al. American Chemical Society Sustainable Chemistry & Engineering, 1(2):254-9, 2013.
[6] Rovani S, Santos JJ, Corio P, Fungaro DA. American Chemical Society Omega, 3(3):2618-27, 2018.
[7] Anuar MF, Fen YW, Zaid MHM, Matori KA, Khaidir REM. Results in Physics, 11:1-4, 2018.
[8] Zhang Y, Xu W, Wang X, Ni S, Rosqvist E, Smått J-H, et al. American Chemical Society Sustainable Chemistry & Engineering, 7(7):6592-600, 2019.
[9] Si L, Shi Z, Hou J, Miao C, Hou Q, Xu Z, et al. American Chemical Society Applied Nano Materials, 5(11):16620-32, 2022.
[10] Olmos-Moya PM, Velazquez-Martinez S, Pineda-Arellano C, Rangel-Mendez JR, Chazaro-Ruiz LF. 187:216-29, 2022.
[11] Prasannan A, Imae T. Industrial & Engineering Chemistry Research, 52(44):15673-8, 2013.
[12] Zhou J, Sheng Z, Han H, Zou M, Li C. Materials Letters, 66(1):222-4, 2012.
[13] Sahoo NK, Jana GC, Aktara MN, Das S, Nayim S, Patra A, et al. Materials Science and Engineering C: Materials for Biological Applications, 108:110429, 2020.
[14] Xue M, Zou M, Zhao J, Zhan Z, Zhao S. Journal of Materials Chemistry B, 3(33):6783-9, 2015.
[15] Liu J, Li R, Yang B. American Chemical Society Central Science, 6(12):2179-95, 2020.
[16] Li M, Chen T, Gooding JJ, Liu J. American Chemical Society Sensors, 4(7):1732-48, 2019.
[17] Aung Y-Y, Kristanti AN, Lee HV, Fahmi MZ. American Chemical Society Omega, 6(28):17750-65, 2021.
[18] ZHANG, Dongqiang, et al. Journal of Biomaterials and Tissue Engineering, 2020.
[19] Zhao X, Dong L, Ming Y, Wang M, Lu Z, Xu Y, et al Talanta, 200:9-14, 2019.
[20] Liang W, Bunker CE, Sun Y-P. American Chemical Society Omega, 5(2):965-71, 2020.
[21] Liu Y, Jiang L, Li B, Fan X, Wang W, Liu P, et al. Journal of Materials Chemistry B, 7(19):3053-8, 2019.
[22] Mao J, Xue M, Guan X, Wang Q, Wang Z, Qin G, et al. Nano Letters, 23(1):124-31, 2023.
[23] Cao M, Li Y, Zhao Y, Shen C, Zhang H, Huang Y. The Royal Society of Chemistry Advances, 9(15):8230-8, 2019.
[24] Lai C, Lin S, Xiong L, Wu Y, Liu C, Jin Y. Diamond and Related Materials, 133:109702, 2023.
[25] Tadesse A, Hagos M, RamaDevi D, Basavaiah K, Belachew N. American Chemical Society Omega, 5(8):3889-98, 2020.
[26] Pho QH, Escriba-Gelonch M, Losic D, Rebrov EV, Tran NN, Hessel V. American Chemical Society Sustainable Chemistry & Engineering, 9(13):4755-70, 2021.
[27] Wang Y, Hu A. Journal of Materials Chemistry C, 2(34):6921-39, 2014.
[28] Liu ML, Chen BB, Li CM, Huang CZ. Green Chemistry, 21(3):449-71, 2019.
[32] Messina M. Nutrients, 8(12), 2016.
[33] Hameed A, Saif MJ, Qayyum MA, Khalid T, Farooq T. Engineered Nanomaterials for Sustainable Agricultural Production, Soil Improvement and Stress Management: Academic Press; 2023. p. 357-85.
[34] Lin J, Huang X, Kou E, Cai W, Zhang H, Zhang X, et al. Biosensors and Bioelectronics, 219:114848, 2023.
[35] Liu L, Qin K, Yin S, Zheng X, Li H, Yan H, et al. Photochemistry and Photobiology, 97(3):574-81, 2021.
[36] Zhao X, Liao S, Wang L, Liu Q, Chen X. Talanta, 201:1-8, 2019.
[37] Patra S, Singh M, Subudhi S, Mandal M, Kumar Nayak A, Sahu BB, et al. Journal of Photochemistry and Photobiology A: Chemistry:114779, 2023.
[38] Raveendran V, Kizhakayil RN. American Chemical Society Omega,

6(36):23475-84, 2021.
[39] Gao Y, Wu Y, Huang P, Wu F-Y. American Chemical Society Applied Nano Materials, 5(8):11539-48, 2022.
[40] Naik V, Zantye P, Gunjal D, Gore A, Anbhule P, Kowshik M, et al. American Chemical Society Applied Bio Materials, 2(5):2069-77, 2019.
[41] Zhao H, Yuan X, Yang X, Bai F, Mao C, Zhao L. Inorganic Chemistry, 60(20):15485-96, 2021.
[42] Adel R, Ebrahim S, Shokry A, Soliman M, Khalil M. American Chemical Society Omega, 6(3):2167-76, 2021.
[43] Giraldo JP, Wu H, Newkirk GM, Kruss S. Nature Nanotechnology, 14(6):541-53, 2019.
[44] Liu S, Tian J, Wang L, Zhang Y, Qin X, Luo Y, et al. Advanced Materials, 24(15):2037-41, 2012.
[45] Ye Y, Zheng L, Wu T, Ding X, Chen F, Yuan Y, et al. American Chemical Society Applied Materials & Interfaces, 12(31):35626-37, 2020.
[46] Yang X-C, Yang Y-L, Xu M-M, Liang S-S, Pu X-L, Hu J-F, et al. American Chemical Society Applied Nano Materials, 4(12):13986-94, 2021.
[47] Zhu L, Shen D, Wang Q, Luo KH. American Chemical Society Applied Materials & Interfaces, 13(47):56465-75, 2021.

A FEASIBILITY STUDY ON APPLYING TREATED WASTEWATER IN THE TIRE CURING PROCESS-Case study of MICHELIN in SAMUT PRAKARN, THAILAND.

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Abstract
This study evaluates the feasibility and effectiveness of using treated wastewater in the tire manufacturing process, focusing on the energy-intensive curing process. A double-pass reverse osmosis (RO) system, enhanced by AFM®ng filtration media, was also mentioned and implemented at Michelin Samut Prakan plant in Thailand to purify wastewater for reuse as boiler-feedwater. Results show a significant reduction in city water consumption and wastewater discharge, aligning with 2050 zero-emission of Michelin goals. The AFM®ng filtration media outperformed traditional sand in wastewater treatment, reducing turbidity by 98.01% and improving the RO system's efficiency. This led to a 26% decrease in overall water consumption. Despite higher initial costs, the system yielded an annual cost saving of 1,409,548 THB and a return on investment (ROI) of 1.86. The study also highlights the environmental benefits, including reduced water consumption and a decrease in CO_2 emissions by 99.49 tons per year. Overall, key findings include significant reductions in water consumption, cost reduction and environmental impact, supporting sustainable industrial practices in line with Thailand's water conservation goals.

Keywords: wastewater reuse, tire manufacturing, reverse osmosis, water conservation, sustainability

1. Introduction

Water scarcity is a critical issue in Thailand, driven by increasing population and economic development. In 2022-2023, Thailand consumed approximately 9,451.36 billion cubic meters of water, with agriculture consuming over half of this demand [1]. To mitigate water scarcity, the Thai government has implemented a water management plan emphasizing water reuse and recycling in the industrial sector [2].

The tire manufacturing industry, particularly the curing process, consumes substantial water due to its reliance on steam generation [3]. The steam generation, which relies on city water, accounts for 52% of the total water used in tire production [4]. Michelin, a leading tire manufacturer, aims to address this issue by reusing treated wastewater leveraging advance treatment technologies like reverse osmosis (RO).

Reverse osmosis has proven to be a versatile and effective technology for treating wastewater in various industrial settings [5]. For instance, two-stage RO systems have been successfully implemented in desalination plants, achieving high recovery rates in producing drinking water from seawater [6]. In the palm oil and dairy industries, RO has facilitated the reuse of wastewater in boilers [7], while in the metal finishing industry, it has led to substantial

water recovery and cost reductions [8] . Moreover, RO-based systems have demonstrated the ability to treat oily wastewater from refineries effectively. Figure 1 presents a sustainable approach to address the water challenges in the tire manufacturing industry. In this process, wastewater undergoes sequential treatment stages (screening, equalization, aerobic digestion, and clarification), followed by filtration and purification through a reverse osmosis system, rendering it suitable for reuse in steam generation.

Michelin, a global leader in tire manufacturing, is committed to producing high-quality tires and driving sustainable economic, social, and environmental growth. With a vision for 2050[9], Michelin aims to achieve zero emissions in both carbon and water consumption[10]. Michelin Co., Ltd. (Samut Prakan Plant), Thailand's leading tire and motorcycle manufacturer, shares this sustainability commitment. Michelin's Samut Prakarn plant, where an RO system was implemented in 2021 to treat and reuse wastewater (as shown in Figure 1), reducing city water reliance by over 30%. It continues to explore new technologies and opportunities for further water reuse, demonstrating its dedication to continuous improvement in water management practices.

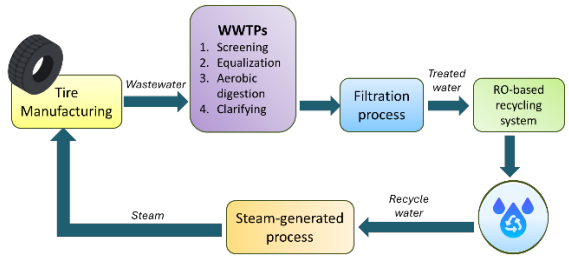

Figure 1. Process flow diagram of Wastewater treatment plant (WWTPs) and RO-based recycling system in a Michelin Co., Ltd. (Samut Prakan Plant) case study.

This research aims to evaluate the feasibility and effectiveness of implementing a sustainable, double-pass RO system to treat wastewater for reuse as boiler feedwater in a Michelin Co., Ltd. (Samut Prakan Plant). This study contributes to significant water savings, cost reduction, accompany with supporting the government's sustainability goals.

2. Objective of this study

2.1 To assess the technical and economic feasibility of utilizing treated wastewater in the tire curing process.

2.2 To identify and evaluate economically viable strategies for recycling and reusing treated wastewater within the tire manufacturing process.

3. Methodology

3.1 Study of improving the efficiency of wastewater treatment using AFM®ng

3.1.1 A pilot-scale study concerned a comparison the wastewater treatment efficiency of AFM®ng filter media (Dryden aqua) and traditional fine sand 1-2 mm. (SAIPRASERT from Ratchaburi, Thailand). Two 16-liter tanks were set up, one filled with sand and the other with a 50:50 mix of AFM®ng grades 0 and 1, with a 20 cm media bed height, as shown in Figure 2.

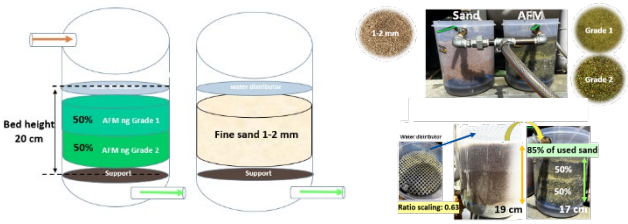

Figure 2. Design a filter tank in the Pilot plant

Effluent from a tire industry wastewater treatment plant, with characteristics summarized in Table 1, was fed into the tanks at a flow rate of 3 LPM. Water samples were collected at a sampling port before routing to each tank and at a port after passing through each tank. The collecting was done twice daily at 9:00 AM and 2:00 PM over 5 days. The collected samples were analyzed for total suspended solids, TSS (APHA 2510B), total dissolved

solids, TDS (APHA 2510B), and turbidity (Nephelometric method).

Table 1. Characteristics of Effluent from WWTPs

Parameters	*unit*	*Mean*
pH		7.2
Temperature	ºC	30
TSS	Mg/l	20
TDS	Mg/L	590
Turbidity	NTU	20

The percentage of removal of each parameter for both AFM®ng and sand media was then calculated using Equation 1 [11] to provide a comparative assessment of their performance in treating the wastewater.

$$\%Removal = \frac{C_0 - C_1}{C_0} \times 100 \quad (1)$$

; where C_0 and C_1 are concentrations before and after treatment, respectively.

3.1.2 A commercial-scale study was conducted to evaluate the treatment efficiency of AFM®ng filter media. An AFM filter tank (1,900 mm x 1,500 mm x 6 mm) was installed as a tertiary treatment in a wastewater treatment plant (WWTP), as shown in Figure 3. The tank was filled with AFM media, utilizing Grade 2 as the base layer, followed by Grade 1 and Grade 0 in ascending order. A turbidity meter (LOVIBOND Model PTV 1000 Basics unit) was installed at the treated water outlet and monitored for 15 days to assess filtration performance.

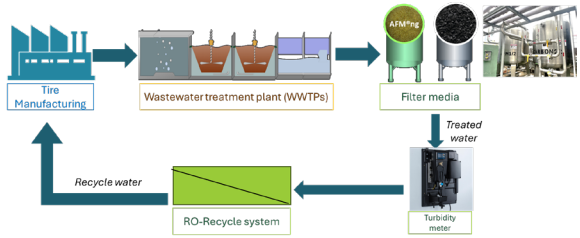

Figure 3. A commercial plant for installing AFM®ng at WWTPs in a Michelin Co., Ltd. (Samut Prakan Plant) case study.

3.2 Study of recycled water in a boiler was done to find out the potential for utilizing recycled water in boiler operations. A study was conducted to evaluate the impact of different ratios of recycled water from the RO-Recycle system to soft city feed water. The ratios were varied at 1:3, 3:1, and 1:1, respectively. Water quality parameters, including pH (APHA 4500-H-B), conductivity (APHA 2510B), total dissolved solids, TDS (APHA 2510B), total hardness (APHA 3220B), calcium hardness (APHA 3220B), M-alkalinity (APHA 3220B), chlorides (APHA 4110B), silica (APHA 3120B), and total iron (APHA 3120B), were analyzed. The cycle of concentration, a critical parameter for assessing the feasibility of scaling up recycled water usage in boiler feed, was calculated using Equation 2 [12].

$$Cycle = \frac{TDS\ of\ Boiler\ water\ (mg/L)}{TDS\ of\ Feeding\ water\ (mg/L)} \quad (2)$$

; where TDS in boiler water is controlled at 2,400 mg/L, according to commercial plant practices

3.3 A double-pass RO system was implemented further to explore the application of recycled water in boiler systems. Recycled water from the RO-Recycle unit was mixed with soft city water at a ratio of 1:3 and fed into the RO system designed for boiler feedwater treatment, as shown in Figure 4. The key water quality parameters monitored in section 3.2 were also analyzed in this stage. Additionally, the percentage of make-up water and blowdown water in the boiler system was calculated using equations 3 and 4, respectively [12].

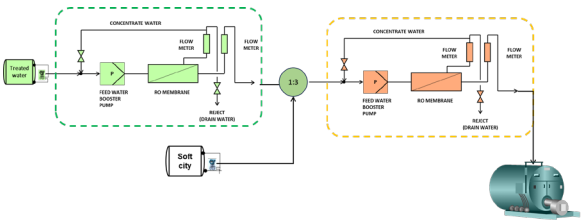

Figure 4 Schematics of Double-pass RO (RO-Recycle to RO for Boiler)

$$\% \, Make\text{-}up = \left(\frac{Q_{Make\text{-}up}}{Q_{Feed}} \right) \times 100\% \quad (3)$$

; where $Q_{Make\text{-}up\ water}$ is the quantity flow of make-up water to the boiler (kg/h), and Q_{Feed} is the quantity flow of total feedwater to the boiler (kg/h).

$$\% \, Blowdown = \left(\frac{Q_{Blowdownr}}{Q_{Feed}} \right) \times 100\% \quad (4)$$

; where $Q_{Blowdown}$ is the quantity flow of Blowdown water to the boiler (kg/h), and Q_{Feed} is the quantity flow of total feedwater to the boiler (kg/h).

3.4 Feasibility analysis

A comprehensive financial and environmental analysis assessed the financial viability of implementing a double-pass RO system for boiler feedwater utilizing recycled wastewater and soft city water.

The financial feasibility of the project was evaluated using the following parameters including Capital Expenditure (CAPEX): represents the initial investment required for installing the new filter tank, piping, and the double-pass RO system. calculated using Equation 5.

$$CAPEX = C_{install} \quad (5)$$

; where $C_{install}$ is cost of installing new filter tank and piping for a double pass RO system for the boiler, THB

Operational Expenditure (OPEX): This encompasses the ongoing costs associated with operating and maintaining the system, including membrane and cartridge filter replacement, chemical feed, electricity, pretreatment unit replacement, cleaning (backwash and CIP), and labor. It is calculated using Equation 6.

$$OPEX = C_{membrane} + C_{chemical} + C_{Electrical} + C_{filter} + C_{cleanning} + C_{labor} \quad (6)$$

; where $C_{membrane}$ (THB/year) is the cost of changing membrane and cartridge filter at the RO-Recycle unit, $C_{chemical}$(THB/year) is the cost for chemical feed into the RO system, $C_{Electrical}$ (THB/year) is the cost of electricity, C_{filter} (THB/year) is the cost for changing of pretreatment unit of RO-Recycle unit, $C_{cleaning}$ (THB/year) is the cost for backwash and CIP unit and C_{labor} (THB/year) is the cost of labor for monitoring Recycle system

% Water Saving is the percentage of water saved is calculated based on the consumption of recycled water from the RO-Recycle unit compared to the consumption of city water, as shown in Equation 7.:

$$\%Water\ saving = \frac{Consump_{Recycled}}{Consump_{City}} \times 100\% \quad (7)$$

; where $Consump_{Recycled}$ (m^3/year) is the total Recycled water consumption, $Consump_{City}$ (m^3/year) is the total city water consumption

The reduction in CO_2 emissions is calculated based on the difference in thermal energy consumption between the project scenario and the reference scenario, using the CO_2 conversion factor from the EPA (50.63 $kgCO_2$ per mmBTU) [13], as shown in Equation 8.

$$Reducing\ CO_2\ Emission\ (tons_{CO_2}) = \frac{TE_{With} - TE_{Without}}{1000} \times f_{CO_2} \quad (8)$$

; where, TE_{with} (mmBTU) is the thermal energy consumption with this project, $TE_{without}$ (mmBTU) is the thermal energy consumption without this project, f_{CO_2} is the Co2 conversion factors from EPA, 2024.

Total cost savings represent the annual savings achieved through reduced city water consumption, treatment costs, and thermal energy costs. They are calculated using Equation 9.

$$Total\ Cost\ saving(THB/year) = S_{cw} + S_{tm} + S_{te} = (Consump_{city} * C_{Soft}) + (Consump_{Blowdown} * C_{tm}) + ((TE_{With} - TE_{Without}) * C_{gas}) \quad (9)$$

; where, S_{cw} is the city water cost saving (THB/year), S_{tm} is the treatment cost saving

(THB/year), S_{te} is the thermal energy cost saving (THB/year), $Consump_{city}$ is total city water consumption (m^3/year), $Consump_{Blowdown}$ is the total water consumption for blowdown (m^3/year), TE_{with} (mmBTU) is the thermal energy consumption with this project, $TE_{without}$ (mmBTU) is the thermal energy consumption without this project and C_{Soft}, C_{tm}, C_{gas}, as shown a Table 2.

Table 2. Data information for calculating feasibility analysis.

	unit	value	Description
C_{Soft}	THB/m3	30.70	Calculate from softener, city water, electrical cost
C_{tm}	THB/m3	8.44	Calculate from chemical, electrical and filter cost
C_{gas}	THB/mmBTU	454.33	Cost of Natural gas[13]

Finally, the project evaluation assessment by using Return on Investment (ROI) using Equation 10 [14].

$$ROI = \frac{Total\ cost\ saving}{CAPEX+OPEX} \quad (10)$$

4. Results and discussion

4.1 Study of improving the efficiency of wastewater treatment using AFM®ng

A pilot-scale study evaluated the comparative efficacy of AFM®ng filter media and traditional fine sand in wastewater treatment. The study focused on the removal efficiency of key water quality parameters: total suspended solids (TSS), total dissolved solids (TDS), and turbidity. The results, illustrated in Figure 5, demonstrating the superior performance of AFM®ng in removing TSS and turbidity compared to sand. AFM®ng achieved a 97% reduction in TSS, significantly surpassing the 89% achieved by sand. This result highlights the enhanced capacity of AFM®ng to filter out suspended particles, a crucial factor in improving water clarity. Regarding turbidity reduction, AFM®ng again outperformed sand, achieving a 92% removal efficiency compared to 76% for sand. This finding underscores the potential of AFM®ng to enhance the aesthetic quality of treated wastewater substantially. While both media exhibited minimal TDS removal, sand demonstrated a slightly higher efficiency (1%) than AFM®ng (5%) [15]. This marginal difference suggests that neither media is primarily designed for TDS removal and may necessitate additional treatment processes to address this parameter effectively.

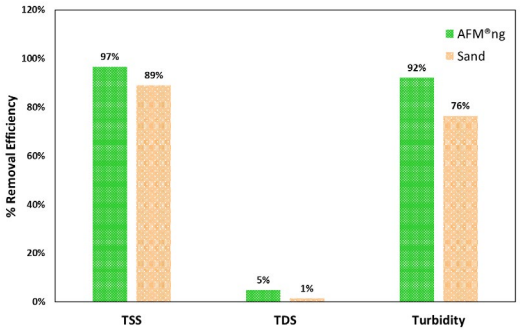

Figure 5. Comparison of removal efficiency between AFM®ng and Tradition sand for TSS, TDS, and Turbidity in WWTPs

Overall, the findings of this pilot study indicate that AFM®ng filter media shows superior performance for wastewater treatment compared to traditional sand in removing TSS and turbidity[16]. This superior performance, coupled with AFM®ng sustainable properties, positions it as a promising alternative filtration in wastewater treatment applications,

After implementing AFM in the Commercial plant and replacing sand with AFM®ng filter media in the existing filtration tanks, a 15-day operational period revealed a significant reduction in effluent turbidity, as shown in Figure 6, which presents a 24-hour turbidity profile. The average turbidity for sand-filtered water was 21.83 NTU, while AFM®ng-filtered water averaged 0.43 NTU. This resulted in a 98.01% decrease in turbidity for water entering the RO-Recycle system when using AFM®ng compared to sand.

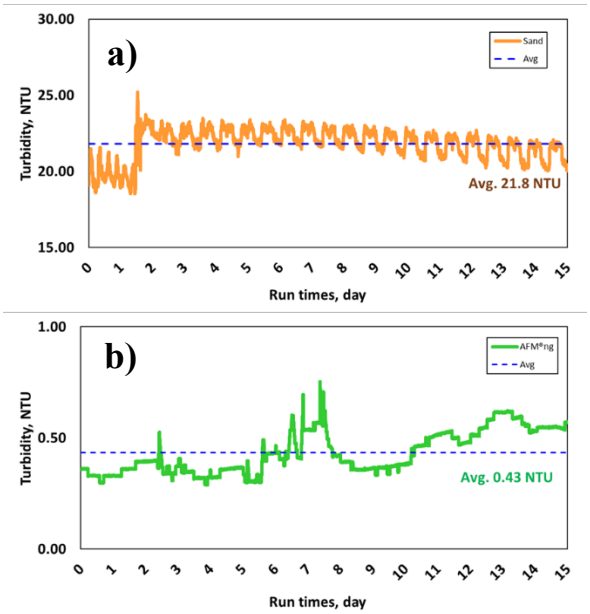

Figure 6. Turbidity Comparison of Sand (a) and AFM®ng (b) Filter Media Over 15 Days of Operation.

Decrease in turbidity directly improved the performance of the RO-Recycle system [17], as evidenced by the increase in recovery rate from 49% to 55% after the implementation of AFM®ng, as shown in Figure 7.

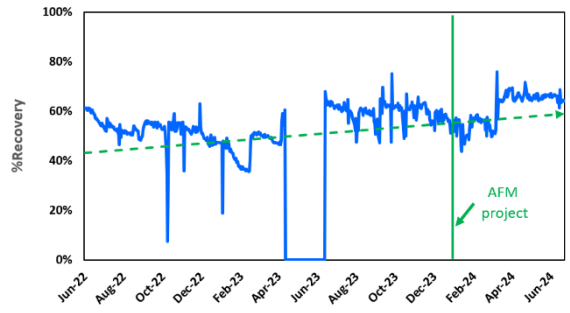

Figure 7. Impact of AFM®ng Implementation on Recovery Rate of RO-Recycle System from Jun-22 to Jun-24

The reduced turbidity mitigated membrane fouling, a common issue with high-turbidity feed water, thus extending the operational lifespan of the membranes and reducing the frequency of backwashing required due to substandard water quality. Furthermore, the improved water quality lessened the workload on the pre-treatment filtration system of the RO-Recycle system, contributing to increased production of recycled water.

4.2 Study of recycled water in a boiler.

A water quality analysis of different ratios of recycled to soft water is shown in Table 3, considering their potential use as feed for RO systems for boilers. The 1:3 ratio of recycled to soft water was optimal, balancing a minimal dissolved solids concentration of 169.4 mg/L and a maximal water efficiency with higher cycles of 14.17. This ratio also maintains acceptable levels for other parameters like pH, hardness, alkalinity, chlorides, silica, and iron, ensuring suitability for RO treatment. Significant improvements in cycles of concentration and reduced city water consumption were observed. While the 3:1 ratio offers higher cycles, its extremely low dissolved solids content can lead to issues like permeate aggression and corrosion. The 1:1 ratio, although moderate, doesn't offer the same optimal balance as the 1:3 ratio. This finding aligns with studies emphasizing the importance of balancing TDS and cycles of concentration in RO systems for boiler feedwater [7], where both excessively high and low TDS can negatively impact performance and longevity[18].

Table 3. Water Quality Analysis of Soft Water and Recycle Water: Soft water at varying ratios for using the feed in RO for the Boiler

Analysis	***Soft***	***Recycle: Soft***		
		1:3	*3:1*	*1:1*
pH	7.51	7.67	7.24	7.44
Conductivity, us/cm	525	308	157.7	278
Dissolved solids, mg/L	288.7	169.4	86.73	152.9
Total Hardness, mg/L	0	0	0	0
Calcium Hardness, mg/L	0	0	0	0
M - Alkalinity, mg/L	92.4	66.4	44.0	64.4
Chlorides, mg/L	99.97	95.85	46.79	50.48
Silica, mg/L	180	14.30	8.60	12.10
Iron total, mg/L	0.02	0.01	0.03	0.03
Cycle	**8.31**	**14.17**	**27.67**	**15,70**

4.3 Double pass-RO for Boiler.

Implementing a double-pass RO system with a 1:3 ratio of recycled water led to substantial water and cost savings. Table 4. illustrates the impact of transitioning feed water to RO for a boiler system on the operational efficiency of a boiler system. The most notable improvement is seen in the cycles of concentration in the boiler parameter, which increases significantly from 18.5 to 97.9. This indicates a substantial reduction in the amount of soft city water required for makeup and a corresponding decrease in blowdown, aligning with findings from studies highlighting the water-saving potential of using recycled water in boiler systems[19].

Table 4. Comparative Analysis of Boiler System Performance with Soft water (Previous situation) and Recycled water: Soft water at 1:3 (Current situation).

Detail	***Soft water (Previous situation)***	***Recycled water: Soft water, 1:3 (Current situation)***
Feedwater flow, kg/h	11,600	11,100
Makeup flow, kg/h	8,260	7,740
Blowdown flow, kg/h	629	114
Condensate return	29%	30.30%
Cycles	18.5	97.9
%Make-up	71.21%	69.73%
%Blow down	5.42%	1.03%

Furthermore, the makeup flow rate decreased from 8,260 kg/h to 7,740 kg/h, while the blowdown flow rate plummeted from 629 kg/h to 114 kg/h, highlighting significant water and cost savings. While the feedwater flow rate saw a minor decrease (11,600 kg/h to 11,100 kg/h), the overall benefits of reduced water consumption and wastewater discharge outweigh this minor adjustment [20]. The observed increase in condensate return rate from 29% to 30.30% further contributes to water conservation efforts and system efficiency. These collective results underscore the positive impact of incorporating recycled water into boiler systems, showcasing its potential to enhance operational efficiency, conserve water resources, and lower operating costs.

City Water consumption after implementing recycled water blended with soft city water at ratio of 1:3 as feed for the RO for the boiler system will start in February. The downward trend line indicates a decrease in water usage over time, with an overall reduction of 26% from January to June (as shown in Figure 8). This significant decrease highlights the positive impact of integrating recycled water into the boiler system, showcasing its potential for substantial water conservation and cost savings. Reduced water usage and wastewater discharge contributed to enhanced operational efficiency and sustainability.

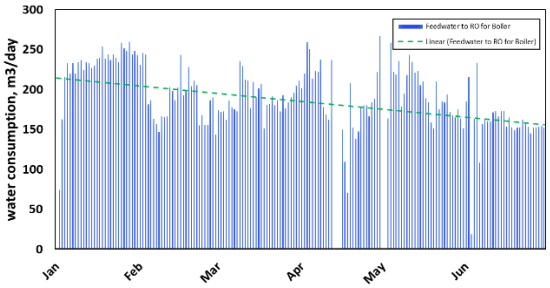

Figure 8. Water consumption for feedwater to RO for boiler system from Jan-Jun, 24.

4.2 Feasibility analysis

The economic and environmental impacts of upgrading a boiler system with AFM®ng filtration in the wastewater treatment plant (WWTP) and double-pass RO for the boiler system were assessed through a comparative analysis, as presented in Table 5. The analysis reveals that while the initial capital expenditure (CAPEX) for installing a new filter tank is higher (2,630,000 THB) than the traditional system (2,407,000 THB) due to the installation of a new filter media tank, the operational expenditure (OPEX) also increases. This increased OPEX is likely attributed to the additional maintenance and

operational requirements of advanced water treatment technologies.

Table 5. Comparative Analysis of Boiler System Costs and Environmental Impact with and without AFM®ng-Enhanced Water Treatment and Double-Pass RO System

Parameters	***With project***	***Without project (Ref.)***
CAPEX, THB	2,630,000	2,407,000
OPEX, THB	333,000	51,000
Water Saving, m3/year	70,000	45,500
%Water Saving	70%	32%
Reduce CO_2 emission, ton CO_2/ year	99.49	
Total saving cost, THB/year	1,409,548	
- City water cost	521,850.00	
- Treatment cost	36,511	
- Energy cost	851,187.00	
ROI	**1.86**	

Despite higher initial and operational costs, the project demonstrates significant financial viability with an annual saving of 1,409,548 THB. This substantial saving is primarily derived from a significant reduction in city water consumption (521,850.00 THB) and a noteworthy decrease in energy consumption (851,187.00 THB). The project's return on investment (ROI) of 1.86 further emphasizes its economic attractiveness, indicating a substantial return for each investment unit.

In addition to the economic benefits, the project also yields notable environmental advantages. The implementation of AFM®ng filtration and double-pass RO leads to a significant water saving of 70,000 m^3/year, representing a 70% reduction compared to the reference scenario. Moreover, the project significantly reduces CO_2 emissions of 99.49 tons CO_2/year, suggesting a more energy-efficient or less carbon-intensive water treatment process.

Overall, the analysis underscores the project's multifaceted benefits. Although the upfront and operational costs are higher, the substantial savings in water and energy consumption and the reduction in CO_2 emissions provide a compelling case for implementing AFM® filtration and double-pass RO in boiler systems. The project has a high ROI and positive environmental impact, which further reinforces its potential for long-term sustainability and economic viability.

5. Conclusion

This study demonstrates the technical and economic feasibility of implementing a double-pass RO system utilizing treated wastewater as boiler feedwater in a tire manufacturing plant. The results highlight the superior performance of AFM®ng filter media compared to traditional sand in wastewater treatment, particularly in reducing turbidity and total suspended solids (TSS). Integrating AFM®ng filtration with a double-pass RO system significantly improved the quality of recycled water, making it suitable for boiler feed and resulting in a 92.5% reduction in turbidity and improving the RO system's efficiency. Implementing this innovative system led to a substantial 26% decrease in overall water consumption. The economic analysis revealed a significant annual cost saving of 1,409,548 THB, attributed to reduced city water and energy consumption. The calculated return on investment (ROI) of 1.86 further underscores the financial viability of this approach. The significant reduction in water consumption and the decrease in CO_2 emissions by 99.49 tons per year contribute to Michelin's sustainability goals and align with Thailand's national water conservation efforts. Overall, this study provides compelling evidence for the feasibility and effectiveness of integrating AFM®ng filtration and a double-pass RO system in the tire manufacturing industry to achieve substantial water savings, cost reductions, and environmental benefits. The findings underscore the potential of this approach to address water scarcity challenges and promote sustainable practices in the industrial sector.

Acknowledgement

This research was supported by Higher Education for industry Consortium (Hi-FI) under Experiential Learning Program, Office of the Permanent Secretary (OPS), Ministry of Higher Education, Science, Research Innovation and Michelin Co., Ltd. (Phra Pradaeng, Thailand).

Reference

[1] ONEP. Thailand State of Environmental Quality Report 2022. Retrieved from https://www.onep.go.th/book/soe2565/, 26 Jun 2024.

[2] MWA. Annual report 2023. Retrieved from https://www.mwa.co.th/about/operate-statistic/annual-report/,

[3] Zhang, J., et al. 2019. Energy-Saving Performance and Production Accuracy of the Direct-Pressure Tire Curing Technology with an Expandable Steel Internal Mold. *Applied Sciences, 10*(1),p. 79.

[4] Rangana, H., et al. 2019. Environmental Pollution By Tire Manufacturing Industry. *International Journal of Scientific & Technology Research, 08*,p. 80-81.

[5] Prisciandaro, M., et al. 2016. Process analysis applied to water reuse for a "closed water cycle" approach. *Chemical Engineering Journal, 304*,p. 602-608.

[6] Davies, P., et al. 2016. Double-acting batch-RO system for desalination of brackish water with high efficiency and high recovery. *Desalination for the Environment–Clean Energy and Water, Rome, 221*,p. 23-25.

[7] Koo, C. H., & Mohammad, A. W. 2011. Recycling of oleochemical wastewater for boiler feed water using reverse osmosis membranes—A case study. *Desalination, 271*(1-3),p. 178-186.

[8] Petrinic, I., et al. 2015. A feasibility study of ultrafiltration/reverse osmosis (UF/RO)-based wastewater treatment and reuse in the metal finishing industry. *Journal of cleaner production, 101*,p. 292-300.

[9] Michelin Co. Ltd. MICHELIN, leader in sustainable mobility. Retrieved from https://www.michelin.com/en/sustainability/mobility, 1 Jul 2024.

[10] Michelin Co. Ltd. Environmental policy Chapter Specific to Production Facilities and Other Sites. Retrieved from https://www.michelin.com/en/sustainability/company/planet, 1 Jul 2024.

[11] Kuokkanen, V., et al. 2013. Recent applications of electrocoagulation in treatment of water and wastewater—a review. *Green and sustainable chemistry, 3*(2),p. 89-121.

[12] Daniel, F. 2009. *Nalco Water Handbook, Third Edition* (Third Edition ed.). New York: McGraw-Hill Education.

[13] Energy Policy and Planning Office, M. o. E., Thailand. Natural Gas Price Situation on June 10 - 14, 2024. Retrieved from https://www.eppo.go.th/index.php/th/petroleum/gas/ngv-situlation, 2 Jul 2024.

[14] Gottlieb, P. D., et al. 2022. An online tool for estimating return-on-investment for water recycling at nurseries. *HortTechnology, 32*(1),p. 47-56.

[15] Krishnamurthy, N., et al. 2023. *Comparative study of Conventional and other Filter Medium.* Paper presented at the IOP Conference Series: Earth and Environmental Science.

[16] Cescon, A., & Jiang, J.-Q. 2020. Filtration process and alternative filter media material in water treatment. *Water, 12*(12),p. 3377.

[17] Sadeddin, K., et al. 2011. Removal of turbidity and suspended solids by electro-coagulation to improve feed water quality of reverse osmosis plant. *Desalination, 268*(1-3),p. 204-207.

[18] Venzke, C. D., et al. 2017. Application of reverse osmosis to petrochemical industry wastewater treatment aimed at water reuse. *Management of Environmental Quality: An International Journal, 28*(1),p. 70-77.

[19] Ozbey-Unal, B., et al. 2020. Treatment of organized industrial zone wastewater by microfiltration/reverse osmosis membrane process for water recovery: From lab to pilot scale. *Journal of Water Process Engineering, 38*,p. 101646.

[20] Obotey Ezugbe, E., & Rathilal, S. 2020. Membrane technologies in wastewater treatment: a review. *Membranes, 10*(5),p. 89.

Consolidation of Mn-Zn ferrite and sintering ceramic by cold sintering process

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Abstract
MnZn ferrite powder (Mn0.8Zn0.2Fe2O4) was synthesized through a co-precipitation method. The MnZe ferrite nanoparticles were cold sintered at 160 °C for 3h to form bulk samples.A liquid medium consisted of an oxalic acid solution and deionized water. The achieved relative densities of the sample were approximately 85%. The effect of the solvent was investigated, including phase analysis and crystallography using X-ray diffraction (XRD), as well as the magnetic properties using a vibrating sample magnetometer (VSM). XRD analysis showed MnZn ferrite phase for particles and bulk samples without any additional phases. Field emission scanning electron microscopy (FESEM) was used to study the microstructure of the sample and found that MnZn ferrite particles are connected to from the bulk structure. Magnetic properties by oxalic acid solution with maximum magnetic saturation value (Ms) at 47.58 emu/g. Remanence (Mr)120.77 emu/g , Coercivity (Hc) 19.63 kOe were magnetic behavior exhibited characteristics suitable for a versatile range of applications.
Keywords: Co-precipitation, cold sintering process, Mn-Zn ferrite, magnetic properties.

1. Introduction

The modern electronics materials industry is rapidly gaining attention for its potential to develop various daily convenience devices. This includes materials such as ferroelectric, thermoelectric, dielectric, and others. Among these, ferrite materials, or ceramic magnets, are developing rapidly. These materials possess high magnetic properties and have diverse applications in various fields such as industry, medicine, and agriculture. Each type of magnetic ceramic material has different ratios or proportions of metals, which can be categorized into two types: 1) Soft ferrite and 2) Hard ferrite, each with distinct magnetic properties.

In diverse research, manganese-zinc ferrite, a type of soft magnetic ceramic material, has shown highly interesting magnetic properties. These properties include high electrical resistance, high permeability (which indicates good electrical signal transmission), and high saturation magnetization, which is a magnetic property indicating the maximum energy storage capacity of a material when subjected to a magnetic field. These characteristics result from the alignment of magnetic moments within the material in accordance with the direction of the magnetic field. Manganese-zinc ferrite also exhibits high-temperature resistance. These attributes make it highly suitable for manufacturing electronic and magnetic electronic devices, meeting the demands in both scientific and industrial fields. It is one of the most efficiently used types of magnetic ceramics.

In 2023, Mingming Si [2] studied the properties of manganese-zinc ferrite, which depend on the synthesis methods. Various techniques for preparing manganese-zinc ferrite include sintering, solid-state reactions, 3D printing, microwave sintering, and spark plasma sintering. Most of these processes require high sintering temperatures to achieve the desired density, typically above 1,400°C, resulting in high energy consumption, costs, and carbon dioxide emissions. Therefore, researchers have been exploring methods to reduce the sintering temperature of manganese-zinc ferrite while maintaining its

electrical signal transmission capability and magnetic properties. Mingming Si [2] investigated the density of high-concentration manganese-zinc ferrite through a cold sintering process assisted by a two-step sintering method. By comparing the relative density of cold-sintered samples at different temperatures, times, and pressures, the optimal cold sintering parameters were found to be 300°C for 2.5 hours under 450 MPa pressure. Additionally, the use of organic salts and water in liquid form aided the cold sintering process. When the solution was removed, a dissolution-precipitation process occurred, leading to the highest relative density achieved through the cold sintering process.

The capabilities mentioned above aim to improve or apply materials using techniques to lower the sintering temperature. This process, known as the Cold Sintering Process (CSP), is employed to create ceramic materials at temperatures below the melting point of the material, thereby enabling grain bonding and increasing ceramic density, even at temperatures below 300°C. CSP's primary advantages include reducing production temperatures and applying lower pressure, which minimizes the risk of material damage or adverse changes during the ceramic manufacturing process. By leveraging these low-temperature and low-pressure conditions, CSP effectively reduces the risk of material damage and undesirable alterations during production. The process involves adding solutions that enhance material density efficiently.

Yao Ying and colleagues [3] investigated manganese-zinc ferrite synthesized using CSP at 330°C under pressure with ethanol acetate solution. The study examined the effects of varying pressures and annealing temperatures on the product's density. Additionally, the research explored the microstructure and magnetic properties of manganese-zinc ferrite produced through CSP, presenting the use of oxalic acid solution in the cold sintering process. Oxalic acid acts as a reducing agent, facilitating the reduction of metal ion oxidation states and forming stable metal ion complexes. This incorporation of oxalic acid in the cold sintering process offers significant advantages in molding ceramic materials.

Despite various research efforts, CSP temperatures remain relatively high, typically between 250-300°C under pressures around 450 MPa. These conditions do not fully align with the desired objectives, prompting researchers to seek further reductions in CSP temperatures while enhancing the efficiency of manganese-zinc ferrite. Consequently, manganese-zinc ferrite was synthesized using the co-precipitation method for easier synthesis and better size control, improving its magnetic properties. The ferrite was cold-sintered at 160°C under 400 MPa pressure with oxalic acid solution to enhance material density.

2. Experimental Section

Chemicals and Reagents.

Magnesium (II) Chloride Hexahydrate ($MgCl_2 \cdot 6H_2O$) was purchased from RCI Labscan (Bangkok). Zinc (II) Chloride ($ZnCl_2$) was purchased from RCI Labscan (Bangkok). Iron (III) Chloride ($FeCl_3$) was purchased from EMSURE (Germany). Oxalic acid ($C_2H_2O_4$). Sodium Hydroxide (NaOH). Deionized Water.

Instrumentation and Characterization.

X-ray Diffraction (XRD) from PANalytical (EMPYREAN) (operation at 2Θ = 20°-80°). Scanning Electron Microscopy (SEM), and Vibrating Sample Magnetometry (VSM) were used to evaluate the magnetic properties, electrical conductivity, and resistance characteristics of manganese-zinc ferrite. Field Emission Scanning Electron Microscopy (FESEM) (Hitachi SU8030) and Focus Ion Beam were used to investigated morphology of the samples. Fourier Transform Infrared Spectroscopy (FT-IR) was performed.

Synthesis of manganese-zinc ferrite nanoparticles

Manganese-zinc ferrite was synthesized using the co-precipitation method due to its straightforward procedure. $MnCl_2$, $FeCl_3$, and $ZnCl_2$ were used as precursor solutions. Initially, solutions of $MnCl_2$ (0.8M), $ZnCl_2$ (0.2N), and $FeCl_3$ (1M) were prepared, each with a volume of 50 mL, and dissolved in 50 mL of DI water. The three solutions were then mixed together on a hot plate stirrer at 80°C for 60-70 minutes until an orange-brown solution was observed. NaOH solution, prepared at a concentration of 0.8M and a volume of 800 mL, was used as the precipitating agent. This NaOH solution was gradually added dropwise to the mixed precursor solution to induce precipitation, adjusting the pH to approximately 12. Once the pH reached around 12, the mixture was centrifuged for 60-70 minutes at 80°C. The precipitate was then allowed to rest at room temperature for 3-4 hours to facilitate further precipitation of iron particles. The resulting precipitate was centrifuged and washed with distilled water 3-4 times, followed by washing with ethanol 3-4 times, to achieve a pH of around 6. The washed particles were then dried at 80°C for 4 hours, or until fully dried. Finally, the dried manganese-zinc ferrite nanoparticles were ground into a fine powder, as illustrated in the synthesis diagram of manganese-zinc ferrite nanoparticles. This method ensures the efficient synthesis of manganese-zinc ferrite with controlled particle size and high purity, suitable for various applications.

Cold sintering process

The preparation of manganese-zinc ferrite compacts involves leveraging liquid assistance for compaction and realignment. In this study, deionized water and oxalic acid solutions were used, divided into eight samples, to examine their effects on the cold sintering process. The procedure begins with preparing 1 gram of synthesized manganese-zinc ferrite powder. This powder is mixed with varying volumes of deionized water (150 µl, 200 µl) and oxalic acid solutions at concentrations of 0.1M, 0.3M, 0.5M, and 0.8M (150 µl each) using a mortar and pestle. The mixture is then transferred into a mold and compacted at 160°C with a heating rate of 5°C/min and a pressure of 400 MPa for 3 hours. After compaction, the samples are dried at 80°C overnight. These prepared samples will undergo further analysis in subsequent steps.

3. Results and Discussion

Manganese-zinc ferrite characteristics

Iron oxide nanoparticles are compounds with diverse structural formulas. The structural formula of manganese-zinc ferrite ($MnZnFe_2O_4$) represents the primary components of manganese-zinc ferrite, which consist of manganese, zinc, and iron. The ratio of these elements can be adjusted as needed. To test the structural characteristics and composition of the synthesized particles, X-ray diffraction (XRD) analysis was conducted. This analysis illustrates the relationship between the intensity of the diffraction pattern and the angle of X-ray diffraction at 2θ positions of 29.8°, 35.1°, 42.6°, 52.8°, 56.3°, and 61.8°, as shown in Figure 1. The XRD patterns of the eight manganese-zinc ferrite samples were similar, with peaks corresponding to the planes (200), (311), (400), (422), (511), and (440), respectively. These results are consistent with the standard XRD pattern from the International Centre for Diffraction Data (ICDD), reference number 00-010-0467, indicating a cubic crystal structure. The cubic structure was confirmed by the lattice constants calculated from the experimental data, which closely matched the standard values. The detailed lattice constants for all samples are presented in Table 1.

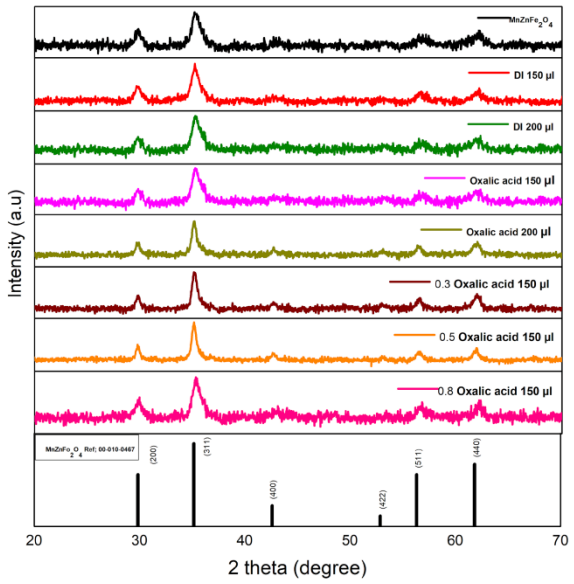


Fig. 1 XRD patterns of manganese-zinc ferrite samples synthesized using the cold sintering process under various conditions.

Table 1 Lattice parameters of the cubic structure of manganese-zinc ferrite synthesized using the cold sintering process under various conditions.

Samples	Lattice parameters (Å)
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 150 µl /DI	8.836
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 200 µl /DI	8.836
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 150 µl /Oxalic acid	8.836
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 200 µl /Oxalic acid	8.836
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 150 µl/0.1Oxalic acid	8.836
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 150 µl/0.3Oxalic acid	8.834
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 150 µl/0.5Oxalic acid	8.834
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 150 µl/0.8Oxalic acid	8.835

Morphology

The study and analysis of the microstructure of manganese-zinc ferrite were conducted using Field Emission Scanning Electron Microscopy (FE-SEM) to examine porosity and grain size within the material. This analysis is crucial as the microstructure significantly impacts the material's resistive and magnetic properties. The FE-SEM technique allowed for the determination of average grain size, with results summarized as follows: Figure 2(A) shows the particle size and distribution of manganese-zinc ferrite nanoparticles, with an average particle size of 41.038±6.284 nm. Figures 3(A-D) illustrate the morphology of samples treated with oxalic acid solutions and deionized water after the cold sintering process at 160°C. This process resulted in a reduction in porosity and an increase in average grain size, with values of 49.745±10.67 nm, 49.026±8.899 nm, 51.933±6.884 nm, and 52.550±8.899 nm, respectively. This is consistent with density data, which showed an increase in material density, as depicted in Figures 3(A-B). The composition of the solutions led to induction, demonstrating the connection between grain particles and deionized water, resulting in densities of 81% and 80%, respectively. Conversely, Figures 3(C-D) reveal that oxalic acid solutions effectively connected grain sizes, achieving higher densities of up to 85%. Figures 3(D-E) further illustrate the uniformity in grain connectivity with oxalic acid solutions, resulting in densities of 85%, 83%, 84%, and 85% as shown in Table 2. This process not only enhances the density of the material at lower temperatures but also reduces grain growth, a beneficial property for developing materials that require high density and grain growth inhibition.

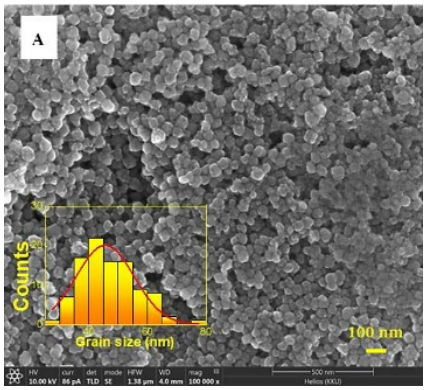


Fig. 2 FE-SEM image of the sample (a) powdered manganese-zinc ferrite at a magnification of 100,000x.under various conditions.

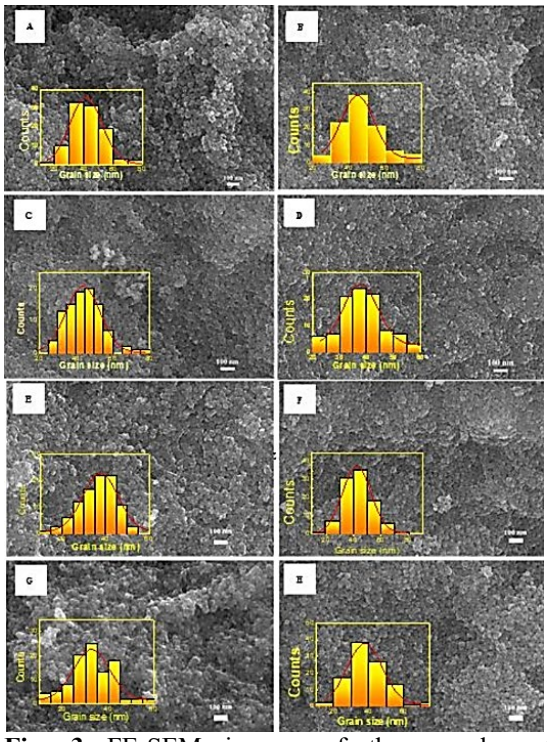


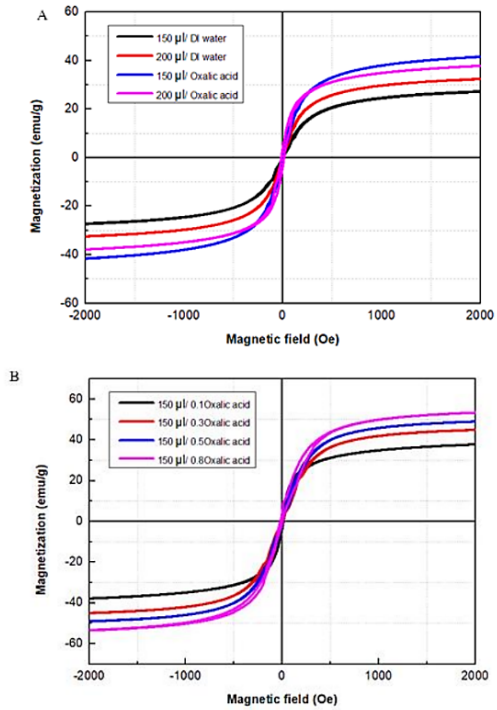
Fig. 3 FE-SEM images of the samples at a magnification of 100,000x: (A) 150 µl DI, (B) 200 µl DI, (C) 150 µl Oxalic acid, (D) 200 µl Oxalic acid, (E) 150 µl 0.1M Oxalic acid, (F) 150 µl 0.3M Oxalic acid, (G) 150 µl 0.5M Oxalic acid, (H) 150 µl 0.8M Oxalic acid.

Table 2 Average grain size of manganese-zinc ferrite

Samples	Diameters (nm)	Density (%)
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 150 µl /DI	49.74±10.67	±81%
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 200 µl /DI	49.02±8.89	±80%
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 150 µl /Oxalic acid	51.93±6.88	±85%
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 200 µl /Oxalic acid	52.55±8.89	±85%
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 150 µl/0.1Oxalic acid	44.44±6.88	±85%
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 150 µl/0.3Oxalic acid	45.18±7.22	±83%
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 150 µl/0.5Oxalic acid	45.22±8.88	±84%
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 150 µl/0.8Oxalic acid	45.85±8.66	±85%

Magnetism of Manganese-Zinc Ferrite

Magnetic properties were studied using a vibrating sample magnetometer (VSM) to analyze the magnetic characteristics of the samples. The M-H curve, which shows the relationship between magnetization (M) and magnetic field (H) for manganese-zinc ferrite samples processed under various cold sintering conditions, is depicted in Figure 4. The VSM measurements indicate the saturation magnetization (Ms) and coercive field (Hc), as summarized in Table 3. The M-H curves illustrate soft magnetic behavior for the samples, with the highest saturation magnetization (Ms) observed for the sample treated with 150 µl of oxalic acid solution, indicated by the blue dashed line, yielding ±49.29 emu/g, and a coercive field (Hc) of ±27.67 emu/g. In comparison, samples with black, red, and pink dashed lines exhibit lower coercive fields (Hc), likely due to the effective dissolution properties of oxalic acid in removing iron oxides and enhancing grain connectivity while reducing porosity within the material's structure during cold sintering. This results in higher saturation magnetization values, consistent with the previously mentioned density values. The M-H curves show narrower hysteresis



loops for the blue and pink dashed lines, which may be attributed to the chemical properties of oxalic acid. Generally, oxalic acid, while similar to water, has better penetration and structural disruption capabilities, leading to improved dissolution of iron oxides and narrower hysteresis loops. This suggests that oxalic acid is an excellent additive for cold sintering processes of magnetic materials, enhancing performance and yielding favorable results for manganese-zinc ferrite.

Fig. 4 Magnetic hysteresis curves for manganese-zinc ferrite processed by cold sintering using VSM (A) using 150 µl and 200 µl of deionized water and oxalic acid solutions, respectively, and (B) oxalic acid concentrations of 0.1, 0.3, 0.5, and 0.8 M at a volume of 150 µl, with an external magnetic field of 30,000 Oe.

Table 3 Magnetization (Ms) and coercivity (Hc).

Samples	Ms (emu/g)	Hc (Oe)
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 150 µl /DI	±33.81	±18.04
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 200 µl /DI	±38.19	±28.98
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 150 µl /Oxalic acid	±49.29	±27.67
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 200 µl /Oxalic acid	±44.72	±29.83
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 150 µl/0.1Oxalic acid	±49.29	±27.67
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 150 µl/0.3Oxalic acid	±50.61	±16.91
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 150 µl/0.5Oxalic acid	±54.71	±14.48
$Mn_{0.8}Zn_{0.2}Fe_2O_4$ 150 µl/0.8Oxalic acid	±60.32	±11.86

Impedance Experiment

The results of the complex impedance study for samples subjected to cold sintering at 160°C under various conditions are shown in Figure 5(A). This figure illustrates the impedance properties, indicating the material's electrical resistance behavior. The study may reveal the material's ability to generate and resonate within a magnetic field and its relationship with the frequency of the applied electrical signals. The graphs depict the real and imaginary components of impedance. The graph for the maximum frequency shows that using a 0.1 M oxalic acid solution at 150 µl leads to higher impedance values compared to higher concentrations of oxalic acid or deionized water. This is due to oxalic acid's ability to alter the electrical properties of the material. Increasing the concentration of oxalic acid can enhance these properties, such as increasing the impedance frequency. The frequency values differ based on the varying solutions used in the different experimental conditions. Figures 5(B) and 5(C) display the impedance graphs. Figure 5(A) shows the use of deionized water in volumes of 150 and 200 µl, where the graph reveals two impedance peaks: one for grain resistance and one for grain boundary resistance. The presence of deionized water during the cold sintering process causes poor grain connectivity,

leading to electron collisions and significant porosity. This results in lower magnetic efficiency. In contrast, Figure 5(C) illustrates the use of oxalic acid solutions in volumes of 150 and 200 µl, showing a single impedance peak that indicates better grain connectivity. The electron flow is more efficient with oxalic acid compared to deionized water.

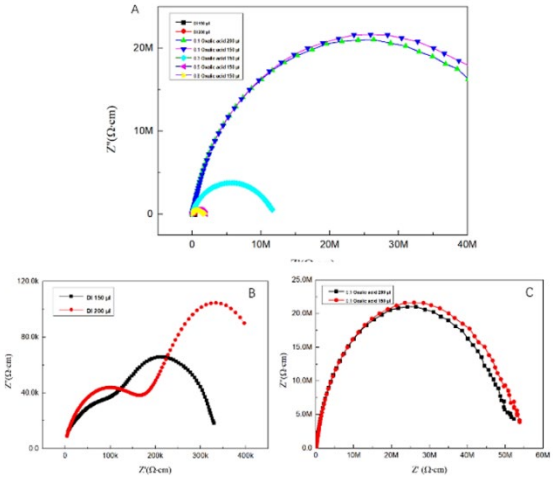


Fig. 5 (A) The relationship between the real and imaginary components of impedance, (B) The relationship between the real and imaginary components of impedance using deionized water, and (C) using oxalic acid.

Considering the aforementioned points, Figure 6 (A-E) presents graphs illustrating the relationship between the real and imaginary components of impedance for oxalic acid solutions with concentrations of 0.1, 0.3, 0.5, and 0.8 M at a volume of 150 µl. Increasing the concentration of oxalic acid affects the impedance values. As shown in Figure 6 (A), the resistance tends to decrease consistently with higher concentrations of oxalic acid. This is because oxalic acid serves effectively as a grain connector, facilitating easier electron movement and resulting in higher electrical conductivity. Higher electrical conductivity typically correlates with lower magnetic properties due to the reduced resistance within the material. Figures 6 (B-E) show that the highest impedance resistance is represented by the black line for the oxalic acid solution with a concentration of 0.1 M. In contrast, solutions with concentrations of 0.3, 0.5, and 0.8 M demonstrate a decreasing trend in resistance. This reduction in resistance aligns with increased magnetic properties, as evidenced by the higher saturation magnetization (Ms). The lower resistance results in higher electrical conductivity and consequently lower magnetic properties, due to the enhanced ease of electrical current flow through the material.

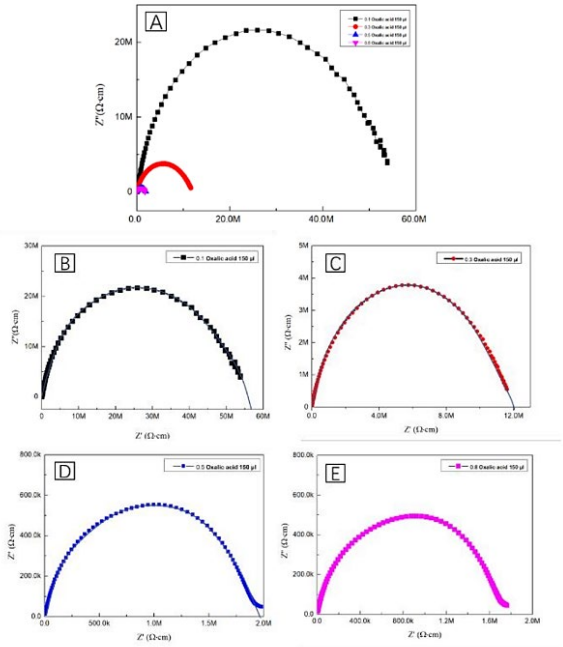


Fig. 6 Graphs showing the relationship between the real and imaginary components of impedance:(A) Oxalic acid concentrations of 0.1, 0.3, 0.5, and 0.8 M at a volume of 150 µl, (B) 0.1 M, (C) 0.3 M, (D) 0.5 M, (E) 0.8 M.

4. Conclusion

This study investigates the synthesis of manganese-zinc ferrite through co-precipitation and subsequent cold sintering at 160°C under various conditions. The process involves eight different samples using different volumes of deionized water and oxalic acid solutions at concentrations of 0.1, 0.3, 0.5, and 0.8 M, with volumes of 150 and 200 µl respectively. The crystalline structure was examined using X-ray diffraction (XRD),

confirming that manganese-zinc ferrite has a cubic structure, and no impurities were detected in any phase before or after processing. The results align with the standard XRD pattern from the International Centre for Diffraction Data (ICDD) with reference number 00-010-0467, and lattice parameters calculated from the experiments are close to the standard values.

Microstructural analysis of the manganese-zinc ferrite was conducted using Field Emission Scanning Electron Microscopy (FE-SEM) to assess the structural and material properties. This analysis is crucial for understanding the internal structure of manganese-zinc ferrite and its impact on magnetic and electrical resistive properties. The FE-SEM results reveal an average particle size of 41.038±6.284 nm. Additionally, the study found that using oxalic acid solutions and varying sintering temperatures significantly affect the density and grain size within the material, resulting in a density increase up to 85% and a reduction in porosity, which in turn affects grain growth.

Subsequently, magnetic properties of the manganese-zinc ferrite samples were assessed using a Vibrating Sample Magnetometer (VSM). The analysis of the M-H curves and measurements of saturation magnetization (Ms) and coercivity (Hc) demonstrated that increasing the concentration of oxalic acid resulted in a clear increase in Ms, with the highest value of ±60.32 emu/g observed at the highest concentration of oxalic acid. Furthermore, Hc showed a decreasing trend with higher concentrations of oxalic acid, indicating improved magnetic dissolution and retention capabilities of the material due to the properties of oxalic acid.

Finally, impedance results revealed that different concentrations of oxalic acid affect the impedance frequency. Higher frequencies were observed with the lowest concentration of oxalic acid, leading to higher resistance and lower conductivity compared to higher concentrations or deionized water. Oxalic acid's ability to alter the electrical properties of the material impacts its magnetic field. Increasing oxalic acid concentration enhances the material's electrical and magnetic properties. The experiment demonstrated that the density of the material after cold sintering increased to a maximum of 85%, positively affecting magnetic properties. To further enhance density and magnetic performance, additional annealing at various temperatures may be explored for better efficiency and application in desired fields.

Reference

[1] Preeti Thakura,Deepika Chahara ,et al. A review on MnZn ferrites: Synthesis, characterization and applications' 2020, Pages 15740-15763.

[2]Mingming Si a, Xinyi Li a, Changli Fu a, Cold sintering assisted processing of Mn-Zn ferritesNovember 2023, Pages 6145-6153

[3]Preparation of Densified Fine-Grain High-Frequency MnZn Ferrite Using the Cold Sintering Process 2023 May; 16(9): 3454.

[4] G. Kogias, V.T. Zaspalis, Temperature stable MnZn ferrites for applications in the frequency region of 500 kHz, Ceram. Int. 42 (2016) 7639–7646

[5]M. Saqib1 et al. Temperature-Dependent Variations in Structural, Magnetic, and Optical Behavior of Doped Ferrites Nanoparticles. 19 July (2020)

[6]Kefeni, K.K., Msagati, T.A.M. & Mamba, B.B. (2017). Ferrite nanoparticles: Synthesis, characterisation and applications in electronic device.Materials Science and Engineering: B, 215, 37-55.

[7]Adschiri, T., Hakuta, Y., Sue, K. & Arai, K. (2001). Hydrothermal synthesis of metal oxide nanoparticles at supercritical conditions. Nanoparticle Research, 3, 227–235.

[8]K.E. Sickafus, J.M. Wills, N.W. Grimes, Structure of spinel, J. Am. Ceram. Soc. 82 (2004) 3279–3292.

[9] S. Sanatombi, S. Sumitra, S. Ibetombi,

Influence of sintering on the structural, electrical, and magnetic properties of Li–Ni–Mn–Zn ferrite synthesized by citrate precursor method, Iran. J. Sci. Technol. Trans. A-Science 42 (2018) 2397–2406,

[10]J. Kalarus, G. Kogias, D. Holz, V.T. Zaspalis, High permeability-high frequency stable MnZn ferrites, J. Magn. Magn Mater. 324 (2012) 2788–2794

[11]R. Islam, M.A. Hakim, M.O. Rahman, H. Narayan Das, M.A. Mamun, Study of the structural, magnetic and electrical properties of Gd-substituted Mn-Zn 559 (2013) 174–180

[12]P. Mathur, A. Thakur, M. Singh, IMPACT OF PROCESSING AND POLARIZATION ON DIELECTRIC BEHAVIOR OF NixMn0.4-xZn0.6Fe2O4SPINEL FERRITES, International Journal of Modern Physics B 23 (2009) 2523–2533

[13]A. Verma, M.I. Alam, R. Chatterjee, T.C. Goel, R.G. Mendiratta, Development of a new soft ferrite core for power applications, J. Magn. Magn Mater. 300 (2006) 500–505

[14] S. Nakagawa, S. Saito, T. Kamiki, S.-H. Kong, Mn–Zn spinel ferrite thin films prepared by high rate reactive facing targets sputtering, J. Appl. Phys. 93 (2003) 7996–7998

[15]J. Azadmanjiri, Preparation of Mn-Zn ferrite nanoparticles from chemical sol-gel combustion method and the magnetic properties after sintering, J. Non-Cryst. Solids 353 (2007) 4170–4173

[16]F. Ameen Ramiza, S.K. Ajmal, M.B. Khan, A. Nasim, Y. Jamil, K. Kashif, S. Amira, Effect of UV radiations to control particle size of Mn-Zn spinel ferrite nano-particles, IOP Conference Series: Materials Science and Engineering, Institute of Physics Publishing, 2016,

[17]M. Maisnam, S. Phanjoubam, Frequency dependence of electrical and magnetic properties of Li-Ni-Mn-Co ferrites, Solid State Commun. 152 (2012) 320–323

[18]H. Mohseni, H. Shokrollahi, I. Sharifi, K. Gheisari, Magnetic and structural studies of the Mn-doped Mg-Zn ferrite nanoparticles synthesized by the glycine nitrate process, J. Magn. Magn Mater. 324 (2012) 3741–3747

[19]Pellicer, E., Rossinyol, E., Cabo, M., Lopez-Ortega, A., Estrader, M., Surinach, S. et al. (2011). Oxide-Matrix Based Nanocomposite Materials for Advanced Magnetic and Optical Functionalities. Retrieved May 20, 2020

[20]Gupta, S.K., Kumar, A., Raja, A.R., Vashista, M. & Yusufzai, M.Z.K. (2020). Magnetic hysteresis loop behaviour of welded ferritic stainless steel 409L with the variation of magnetic field intensity. Materials Today: Proceedings, 26, 1681-1685

[21]B. Skołyszewska, W. Tokarz, K. Przybylski, Z. Kakol, Preparation and magnetic properties of MgZn and MnZn ferrites, Physica C: Superconductivity and Its Applications 387 (2003) 290–294

[22]Cekdar Vakifahmetoglu, A review on MnZn ferrites: Synthesis, characterization and applications, Department of Materials Science and Engineering, Izmir Institute of Technology, 35430 Urla, Izmir, Turkey,2020

[23]Reza Aref, Niklas Jantunen * , Sami Virolainen, Recovery of oxalic acid from hydrochloric acid and cobalt containing hydrometallurgical side-stream by solvent extraction, Minerals Engineering 209 (2024) 108617

[24]Y. Ying, Y. Gong, D. Liu, W. Li, J. Yu, L. Jiang, S. Che, Effect of MoO3 addition on the magnetic properties and complex impedance of Mn-Zn ferrites with high Bs and high initial permeability, J. Supercond. Nov. Magn. 30 (8) (2017) 2129–2134.

[25]M.R. Syue, F. Wei, C.S. Chou, C.M. Fu, Magnetic, dielectric, and complex impedance properties of nanocrystalline Mn-Zn ferrites prepared by novel combustion method, Thin Solid Films 519 (23) (2011) 8303–8306.

[26]T.P. Todorova, A. Van den Bossche, V.C.

Valchev, A procedure for the extraction of intrinsic AC conductivity and dielectric constant of N87 Mn-Zn ferrite samples based on impedance measurements and equivalent electrical circuit modeling, IEEE T. Power Electr. 33 (12) (2018) 10723–10735.

Evaluation and Characterization of Lactic Acid Bacteria Isolated from Swine Intestines for potential use as probiotics in animal feed

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Abstract

Currently, probiotics have garnered significant interest for their beneficial uses in promoting health, being used as dietary supplements for both humans and animals. This research aims to isolate bacteria from the Large White swine intestines and test the properties of lactic acid bacteria that have the potential to be efficient probiotics. A total of 106 isolates from the different parts of swine intestines were examined, up to 24 isolates were identified as *Lactobacillus* spp. based on Gram staining and catalase tests. Among these, five isolates exhibited significant antibacterial properties against 10 foodborne pathogens. The isolate L3-42 showed the highest growth inhibition against four pathogens, including *Enterococci* sp.CK, *B. cereus* , EHEC ,and EPEC while L2-51 and L3-31, demonstrated survival under simulated digestive conditions e.g. acidic (pH 3.0) and bile salt (pH 8.0) tolerance , with survival rates up to 95.18%. Antibiotic susceptibility tests revealed the isolate L3-31 was susceptible to six tested antibiotics while L2-52 showed susceptibility to all tested antibiotics. Moreover, after cell surface hydrophobicity was examined, isolate L3-31 showed moderate hydrophobicity (with 62% of HPBI) but relatively low hydrophobicity (<50%) were found in L2-51 and L2-52. This study was finally identified three promising *Lactobacillus* isolates such as L2-51 (*Lactobacillus amylovorus*), L2-52 (*Lactobacillus plantarum*), and L3-31 (*Lactobacillus johnsonii*) with possessed high antimicrobial activity, able to survive under gastrointestinal conditions, sensitive to various antibiotics and showing non- hemolysis activities. This finding may contribute to the development of the effective probiotics for animal health especially in swine or other livestock.

Keywords: probiotics, swine intestines, lactic acid bacteria, *Lactobacillus* spp.

1. Introduction

Lactic acid bacteria (LAB) are a diverse group of Gram-positive bacteria known for their ability to ferment sugars into lactic acid. This group includes genera such as *Lactobacillus, Streptococcus, Enterococcus,* and *Pediococcus,* among others, most LAB strains, such as *L. acidophilus, L. plantarum, L. rhamnosus, L. fermentum, L. brevis, L. casei, L. salivarius,* and *L. bulgaricus*, are generally used as probiotic sources [1]. LAB are widely recognized for their role in the fermentation of dairy, vegetable, and meat products, contributing to the preservation and enhancement of the nutritional and sensory properties of foods [2].

Probiotics, as defined by the World Health Organization (WHO), are "live

microorganisms which, when administered in adequate amounts, confer a health benefit on the host" [3]. LAB are among the most commonly used probiotics due to their long history of safe use and their beneficial effects on both human and animal health. The consumption of probiotics has been associated with various health benefits, including the enhancement of gut microbiota balance, improvement of digestive health, enhancement of the immune response, and potential reduction in the risk of gastrointestinal (GI) infections [4].

In animals, probiotics have been shown to improve growth performance, enhance feed efficiency, and reduce the incidence of enteric diseases. They also play a role in modulating the gut microbiota, which can enhance nutrient absorption and overall health [5]. According to the literature data, a good probiotic must be viable at a rate in the intestine level from 10^7 to 10^9 CFU/g. Survivability through the host GI must be determined through strain production and resistance [1, 3-4].

Given the numerous health benefits of LAB as probiotics, this research aims to isolate lactic acid bacteria from the swine intestines and primary screening for their probiotic properties included their antimicrobial activity against foodborne pathogens, their ability to survive in simulated gastrointestinal conditions, their biosafety by antibiotic susceptibility test and blood hemolysis examination. Finally, the potential probiotic strains were preliminarily identified their species.

2. Materials and Methods

2.1 Isolation and screening of lactic acid bacteria (LAB) from swine intestines

Large white swine intestine samples were collected from PPP slaughterhouse, Nakhon Si Thammarat province, Thailand. Each five samples of small intestines such as duodenum, jejunum, ileum, and large intestine were isolated for potential probiotic bacteria by suspended the samples in a 0.85%(w/v) sodium chloride solution, and were then dilute and followed by spreaded on de Man - Rogosa and Sharp agar (MRS; HiMedia®) containing 50 mg/mL Amphotericin B added as an anti-fungal. . The cultured were then incubated at 37°C under anaerobic conditions for 24-48 h. Each distinctive colonies were purified and were subsequently Gram stained and detection of non-endospore forming and a negative catalase reaction after tested with 3.0% (v/v) H_2O_2 for primary screening of LAB. The purified isolates were finally stored at -80°C in sterile glycerol for long-term storage.

2.2 Antibacterial properties against foodborne pathogens

The isolated LAB were prepared by adjusting the turbidity to 0.5 McFarland (about 10^8 CFU/mL) and were then transferred to MRS broth and incubated at 37°C for 24 h. The obtained cultures were subsequently centrifuged at 5,000 rpm at 4°C for 10 minutes, and the collected cell-free supernatant were neutralized to pH 7.0 before tested against certain foodborne pathogens including *Staphylococcus aureus* ATCC 25923, *Enterococci* sp. CK, *Enterococci* sp. SW, *Bacillus cereus* ATCC 11778, Enterohemorrhagic *Escherichia coli* (EHEC) O157:H7 DMST 12743, Enteropathogenic *Escherichia coli* (EPEC), *Salmonella Typhimurium* ATCC 14028, *Pseudomonas aeruginosa* ATCC 15442, *Enterococcus faecalis* ATCC 29212, *and Klebsiella pneumoniae* ATCC 700603 by agar well diffusion method. Briefly, an inoculum of the active bacterial cultures to be tested were adjusted to 10^8 CFU/mL and were then swabbed onto Mueller Hinton Agar (MHA; Difco™) plates and 6 mm-diameter wells were made using a sterile cork borer. About 20 µL of cell-free supernatant was then added into the wells and allowed to diffuse for 18 h at 37 °C. Finally, the width of the sizes of the inhibition zones were measured in millimeters(mm) [6], indicating the inhibitory

ability against the growth of foodborne pathogenic bacteria. An antimicrobial inhibition zone response were classified as followed: >20 mm (very strong); 10-20 mm (strong); 5-10 mm (medium); <5 mm (weak) while the positive and negative control used were ampicillin and DMSO, respectively.

2.3 Hemolytic activity on blood agar

Streak each LAB on blood agar containing 5% sheep blood (Biomerieux, France) followed by incubation at 37°C for 24 h. The reactions were observed and characterized as beta hemolysis (β-hemolysis) group by clear and complete lysis of red blood cells, alpha-hemolysis (α-hemolysis) group, as indicated by incomplete, green hemolysis, or gamma-hemolysis (γ-hemolysis) group, where no hemolysis occurs [7].

2.4 Acid and Bile salt tolerance

Preparation a simulated gastric acid environment by adjusting MRS broth using 1M HCl to pH 3.0. Subsequently, 100 µL of an inoculated LAB was adjusted to approximately 10^8 CFU/mL and was then transferred to 900 µL of MRS broth with a pH of 3.0 while the bile salt tolerance test was investigated by using 3M NaOH and supplemented with 0.3% bile salt to achieve a final pH at 8.0. Again, 100 µL of the inoculum (about 10^8 CFU/mL) was added into MRS broth with an initial pH of 8.0. The simulated gastrointestinal conditions were incubated at 37°C under anaerobic conditions and assessed the bacterial survival at 0, 3, and 6 hours using the viable plate count method. Calculate the percentage of bacterial survival rate using these following formula[8].

Survival rate (%) = *(log number of cells after testing/log initial number of cells)* x100 (1)

2.5 Antimicrobial susceptibility test

Antibiotics used in this study included Vancomycin (30 µg), Chloramphenicol (25 µg), Erythromycin (10 µg), Gentamicin (120 µg), Ampicillin (25 µg), Ciprofloxacin (10 µg), Tetracycline (30 µg), Streptomycin (10 µg), Nalidixic acid (30 µg), Penicillin G (10 U), Cephalothin (30 µg), Cotrimoxazole (25 µg), and Norfloxacin (10 µg). Briefly, 20 µL of the bacterial cultures adjusted a turbidity to 0.5 McFarland were mixed with 5 mL of molten MRS agar, and were then poured onto MRS agar plates before placing antibiotic discs. The incubation was performed at 37°C for 18 h, followed by assessment of the clear zone diameter around the antibiotic discs. Report results as resistant (R), moderately susceptible (MS), or susceptible (S)[9].

2.6 Determination of the cell surface hydrophobicity

The study of bacterial hydrophobicity is corresponded to the adhesive properties in the intestines, relying on the hydrophobicity characteristic of LAB, the hydrocarbon non-polar (e.g. xylene) is used to demonstrate the cell surface hydrophobicity. The experimental procedure involves adjusting the initial bacterial concentration to about 10^8 CFU/mL in 0.85%(w/v) NaCl, and 3 mL of the bacterial suspension was mixed with 1 mL of xylene. The mixture was vortexed vigorously for 5 minutes and was then incubated at 37°C for 2 h to allow for phase separation. The bottom layer of the liquid phase is then transferred to a 96-well plate, followed by measured the OD at 600 nm. The hydrophobicity index (HPBI) was calculated as given equation [10].

$$\text{Hydrophobicity Index (\%)} = [(A_x - A_t)/A_x] \times 100 \quad (2)$$

Where, A_x was the initial OD_{600} of LAB and A_t was OD_{600} of the water phase after the incubation
The percentage of hydrophobicity was expressed as follows: 0–35%, low hydrophobicity; 36–70%, medium hydrophobicity; and 71–100%, high hydrophobicity

2.7 LAB identification by MALDI-TOF mass spectrometry

The obtained LAB isolates with potential

probiotics properties were determined using MALDI-TOF Microfex mass spectrometry (Bruker, Germany) according to the standard producers protocol [11-12]. The resulting LAB spectra have been identified using the data stored in BioTyper reference library of MALDI-TOF mass spectra and NCBI (The National Center for Biotechnology Information) where the criteria for interpretation of the results were as followed: The high-confidence, the identification index must score ≥ 2. The range from 1.99 to 1.70 indicated low-confidence identification, while the value <1.70 equaled lack of microorganism identification.

2.8 Statistical Analysis

All experiments were performed in triplicates, and all data were expressed as the mean± standard deviation (SD).

3. Results and Discussion

3.1 Isolation and screening of LAB

A total of 106 isolates from small and large intestines of Large White swine exhibiting different colony characteristics were studied their microbiologically using Gram staining and catalase test. Among these, only 24 isolates consisting of the isolate I1-3 1, I1-4 1, I2-5 1, L1-3 1, L1-3 2, L1-4 1, L1-4 2/1, L1-4 2/2, L1-5 1, L2-3 1/1, L2-3 1/2, L2-3 2, L2-4 2, L2-4 3, L2-4 5, L2-4 6, L2-5 1, L2-5 2, L2-5 3, L2-5 5, L2-5 6, L3-3 1, L3-4 2, and L3-5 1 showed rod-shaped morphology and catalase negative indicating the belonging to *Lactobacillus* spp., in addition, all obtained isolates were non-endospore forming.

3.2 Antibacterial properties against foodborne pathogens

The antibacterial properties against certain foodborne pathogens were investigated and the result revealed that 5 isolates such as isolate demonstrated a high effectively inhibition on the tested pathogens as presented in Table1. For example, the isolate L3-42 was able to inhibit the growth of four pathogens including *Enterococci sp.* CK , *B. cereus* , EHEC ,and EPEC with an average inhibition zone about 17.5-23 mm and was classified as strong inhibition intensities followed by the isolate L3-31, L2-51 and L2-56 that were able to inhibit *Enterococci sp.* CK, *B. cereus* , EHEC ,and EPEC with an average inhibition zone about 13.5-21 mm while the isolate L2-52 could inhibit only three pathogens e.g. *Enterococci sp.* CK , EHEC ,and EPEC. There are several reports that most *Lactobacillus* spp. is able to produce antimicrobial substances or various metabolites such as organic acids (acetic acid, propionic acid, butyric acid, and lactic acid) as well as hydrogen peroxide [11]. Interestingly, many lactic acid bacteria produce and secrete the useful substances with the ability to inhibit pathogens mainly bacteriocins, nisin, or pediocin inhibiting cell wall synthesis or create pores in the cell walls of pathogens like *Listeria monocytogenes, Staphylococcus aureus, Escherichia coli, and Salmonella typhimurium* [13] ,[14].

Table 1 An average growth inhibition zone of five potential probiotic LAB isolates against certain foodborne pathogens

Inhibition zone (mm)			
Isolates	L3-31	L3-42	L2-51
Enterococci sp. CK	21±0.5	17.5±0.5	20±0.0
B. cereus	20.5±0.5	23±0.0	21±0.0
EHEC	16.5±0.5	20.5±0.5	21±0.5
EPEC	19.5±0.5	19.5±0.5	17±0.5

Table 1 (cont.)

Inhibition zone (mm)		
Isolates	L2-52	L2-56
Enterococci sp. CK	21 ±0.5	18.5 ±0.5
B. cereus	-	20±0.0
EHEC	22±0.5	18.5 ±0.5
EPEC	16.5 ±0.5	13.5 ±0.0

(-): no inhibition

3.3 Hemolytic activity

A total of 24 bacterial isolates of LAB,

only 21 isolates (I1-31, I1-41, I2-51, L1-31, L1-32, L1-41, L1-4 2/1, L1-4 2/2, L1-51, L2-3 1/1, L2-3 1/2, L2-32, L2-42, L2-45, L2-51, L2-53,L2-55, L2-56, L3-31, L3-42, and L3-51) exhibited α-hemolysis while the rest isolates e.g. L2-4 3, L2-46 and L2-52 resulted in γ-hemolysis (Figure1). Therefore, all of 24 isolates were safe to use as a probiotic supplement in animal feed.

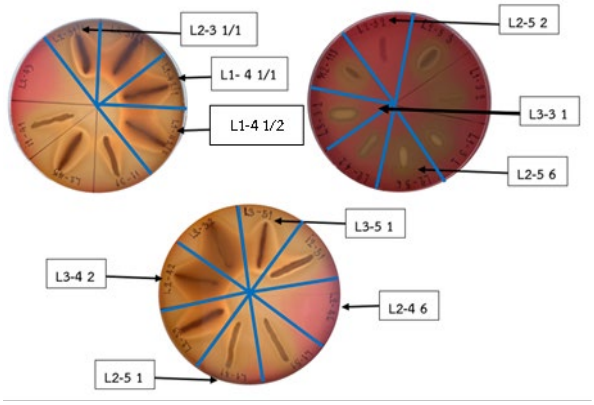

Figure 1 Hemolytic activity of the bacterial isolates of LAB from swine intestines

3.4 Acid and Bile salt tolerance

The ability to withstand in simulated digestive condition was investigated at pH 3.0 for gastric condition and pH 8.0 for intestine condition. The results demonstrated that only 9 isolates (L1-42/1, L1-42/2, L2-46, L2-51, L2-52, L2-56, L3-31, L3-42, and L3-51) were able to survive under the tested conditions (Table 2 and Table 3). Obviously, the survival rates under simulated digestive condition were found to be as high as 95.18% and 94%, respectively by the isolate L2-51.

Table 2 Survival rates of LAB capable of surviving at pH 3 (gastric juice)

Incubation for 6 hours			
Isolates	**Initial CFU/mL**	**Gastric Juice Tolerance**	
		CFU/mL	**%survival**
L1-4 2/1	4.7×10^7	1×10^6	78.21
L1-4 2/2	8×10^5	1×10^5	84.70
L2-46	6.9×10^6	2.1×10^6	92.45
L2-31	6.8×10^5	0	0
L2-51	2.5×10^7	1.1×10^7	95.18
L2-52	6.5×10^7	8.3×10^6	88.56
L2-56	5.6×10^7	1.17×10^7	91.22
L3-31	6.9×10^7	5.3×10^6	85.78
L3-42	9.8×10^7	2.3×10^7	92.12
L3-51	5.1×10^7	5.7×10^5	74.68

Table 3 Survival rates of LAB capable of surviving at pH 8 (bile salt)

Incubation for 6 hours			
Isolates	**Initial CFU/mL**	**Bile salt Tolerance**	
		CFU/mL	**%survival**
L1-4 2/1	4.7×10^7	2.9×10^7	97.27
L1-4 2/2	8×10^5	1×10^5	84.70
L2-46	6.9×10^6	5×10^5	83.33
L2-31	6.8×10^5	0	0
L2-51	2.5×10^7	9×10^6	94
L2-52	6.5×10^7	8.3×10^6	88.56
L2-56	5.6×10^7	5×10^6	86.46
L3-31	6.9×10^7	6.1×10^6	86.56
L3-42	9.8×10^7	1.3×10^7	89.02
L3-51	5.1×10^7	1.03×10^6	95.92

3.5 Antimicrobial susceptibility test

An antimicrobial susceptibility test was performed based on CLSI standard (CLSI Supplement M100S). After tested with 13 antibiotics showing the different mode of actions. The isolate L3-31 was found to susceptible to 6 antibiotics (VA C HLG AMP P NOR) while the isolate L2-52 showed susceptibility to all tested antibiotics (Table 4). However, it has been known that Lactobacilli possessed natural resistance characteristic against certain antibiotics such as erythromycin, tetracycline, and aminoglycosides in nature [15]. These safety reasons is provided to assess the suitability of probiotics for individuals who regularly take medications to prevent the development of antibiotic-resistant bacteria.

Table 4 Inhibition zones of antimicrobial susceptibility test based on CLSI breakpoint

Antibiotic sensitivity	**Isolates**					
	L2-5 2	L3-31	L2-51	L2-56	L2-31	L3-42
VA	S	S	S	R	R	R
C	S	S	S	R	R	R
E	S	R	R	R	R	R

HLG	S	S	S	R	R	R
CIP	S	S	S	R	R	R
AMP	S	R	R	R	R	R
S	S	R	S	R	R	R
NA	S	R	R	R	R	R
TE	S	R	R	R	R	R
P	S	S	I	R	R	I
KF	S	S	R	R	R	R
SXT	S	R	R	R	R	R
NOR	S	R	R	R	R	R

3.6 Determination of the cell surface hydrophobicity

Due to the physical and chemical properties of the microbial strains, specifically testing for hydrophobicity affecting the ability of probiotics to adhere to the intestinal wall was determined by a preliminary non-specific method using non-polar xylene [16-17]. In this study, the cell surface hydrophobicity properties was found a moderate hydrophobicity values about 62% in the isolate L3-31 while the isolate L2-52 and L2-51 exhibited low hydrophobicity (<50%). In comparison with the previous studies, LAB such as *L. salivarius* 2–9 showed up to 95.27% hydrophobicity whereas *L. reuteri* L-3 exhibited moderate hydrophobicity (about 61.15%) [6], in addition, *L. rhamnosus* KLDS , *L. helveticus* IMAU70129 and *L. casei* IMAU60214 had relatively low hydrophobicity about 31% , 35.4% and 38.9% respectively [16]. Therefore, the value of cell surface hydrophobicity can be used to select the probiotic candidates with good adhesion potential to the intestinal epithelium. The hydrophobic character depends on the strain and its specification [17].

3.7 LAB identification by MALDI-TOF mass spectrometry

The potential probiotic LAB that passed all the criteria above, such as the isolate L2-51, L2-52, and L3-31, were further identified by MALDI-TOF mass spectrometry and it had been demonstrated that they were *Lactobacillus amylovorus, Lactobacillus plantarum,* and *Lactobacillus johnsonii,* respectively with a high-confidence identification index (score ≥ 2) as presented in Table 5.

Table 5 Identification of three selected LAB isolates by MALDI-TOF mass spectrometry

Isolates	**Reference strain (NCBI strain no.)**	**Score value**
L2-51	*Lactobacillus amylovorus* DSM 16698	2.19
L2-52	*Lactobacillus plantarum* DSM 2601	2.27
L3-31	*Lactobacillus johnsonii* CIP 103782	2.52

4. Conclusion

This study successfully isolated three potential strains of lactic acid bacteria (LAB) from the Large White swine intestines, and were then identified as *Lactobacillus amylovorus* L2-51, *Lactobacillus plantarum* L2-52, *and Lactobacillus johnsonii* L3-31, exhibiting efficient probiotic properties including the ability to inhibit certain foodborne pathogens, tolerate to acidic and bile salt conditions in the digestive system, and showing the sensitivity to numerous antibiotics and non-hemolysis activity. Additionally, they demonstrated the ability to adhere to intestinal walls as indicated by relatively high hydrophobicity index. These may be considered probiotic candidates for animal nutrition and may have promising performance in swine feed due to their origin of the isolation.

Acknowledgements

This work was financially supported by National Higher Education, Science, Research and Innovation Policy Council, Thaksin University (Research project grant no. TSU-66A105000004) Fiscal Year 2023 and by Thaksin University Research Fund (Research project grant no. TSU-66LGS003) Fiscal Year 2023.

Reference

[1] M. Dumitru *et al.*, "Evaluation of lactic acid bacteria isolated from piglets tract and encapsulation of selected probiotic cells," *Agriculture*, vol. 13, no. 5, p. 1098, 2023.

[2] M. G. Gänzle, "Lactic metabolism revisited: metabolism of lactic acid bacteria in food fermentations and food spoilage," *Curr. Opin. Food Sci.*, vol. 2, pp. 106-117, 2015.

[3] World Health Organization (WHO), *Health and Nutritional Properties of Probiotics in Food Including Powder Milk with Live Lactic Acid Bacteria*, 2001.

[4] M. E. Sanders, D. J. Merenstein, G. Reid, G. R. Gibson, and R. A. Rastall, "Probiotics and prebiotics in intestinal health and disease: from biology to the clinic," *Nat. Rev. Gastroenterol. Hepatol.*, vol. 16, no. 10, pp. 605-616, 2018.

[5] J. A. Patterson and K. M. Burkholder, "Application of prebiotics and probiotics in poultry production," *Poultry Sci.*, vol. 82, no. 4, pp. 627-631, 2003.

[6] P. Wang *et al.*, "Probiotic properties of chicken-derived highly adherent lactic acid bacteria and inhibition of enteropathogenic bacteria in Caco-2 cells," *Microorganisms*, vol. 10, no. 12, p. 2515, 2022.

[7] A. A. Argyri *et al.*, "Selection of potential probiotic lactic acid bacteria from fermented olives by in vitro tests," *Food Microbiol.*, vol. 33, no. 2, pp. 282-291, 2013.

[8] J. Feng, L. Wang, L. Zhou, X. Yang, and X. Zhao, "Using in vitro immunomodulatory properties of lactic acid bacteria for selection of probiotics against Salmonella infection in broiler chicks," *PLoS One*, vol. 11, no. 1, p. e0147630, 2016.

[9] M. L. Hossain, K. Hammer, L. Y. Lim, D. Hettiarachchi, and C. Locher, "Optimisation of an agar overlay assay for the assessment of the antimicrobial activity of topically applied semi-solid antiseptic products including honey-based formulations," *J. Microbiol. Methods*, vol. 202, p. 106596, 2022.

[10] M. C. Collado, J. Meriluoto, and S. Salminen, "Adhesion and aggregation properties of probiotic and pathogen strains," *Eur. Food Res. Technol.*, vol. 226, pp. 1065-1073, 2008.

[11] M. Dec, R. Urban-Chmiel, S. Gnat, A. Puchalski, and A. Wernicki, "Identification of Lactobacillus strains of goose origin using MALDI-TOF mass spectrometry and 16S–23S rDNA intergenic spacer PCR analysis," *Res. Microbiol.*, vol. 165, no. 3, pp. 190-201, 2014.

[12] M. Dec, A. Puchalski, R. Urban-Chmiel, and A. Wernicki, "16S-ARDRA and MALDI-TOF mass spectrometry as tools for identification of Lactobacillus bacteria isolated from poultry," *BMC Microbiol.*, vol. 16, pp. 1-16, 2016.

[13] R. H. Perez, M. T. M. Perez, and F. B. Elegado, "Bacteriocins from lactic acid bacteria: A review of biosynthesis, mode of action, fermentative production, uses, and prospects," *Int. J. Philipp. Sci. Technol.*, vol. 8, no. 2, pp. 61-67, 2015.

[14] B. S. Sivamaruthi, P. Kesika, and C. Chaiyasut, "Thai fermented foods as a versatile source of bioactive microorganisms—A comprehensive review," *Scientia Pharm.*, vol. 86, no. 3, p. 37, 2018.

[15] R. Wongpanti and P. Wongputtisin, "Development of probiotic Lactobacillus johnsonii powder for prevention of pathogenic Helicobacter pylori," Ph.D. dissertation, Maejo Univ., 2021.

[16] L. M. Rocha-Ramírez, U. Hernández-Chiñas, S. S. Moreno-Guerrero, A. Ramírez-Pacheco, and C. A. Eslava, "Probiotic properties and immunomodulatory activity of Lactobacillus strains isolated from dairy products," *Microorganisms*, vol. 9, no. 4, p. 825, 2021.

[17] A. B. Carey, A. Ashenden, and I. Köper, "Model architectures for bacterial membranes," *Biophys. Rev.*, pp. 1-33, 2022.

The 6th KU – IC

International Conference 2024

Subject :

Economics and Applied Economics

Social Return on investment: Economic development to address environmental problems (PM2.5 from forest fires) in rural or developing areas: Kor, Li District, Lamphun Province, Thailand.

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Abstract

This research aims to evaluate the worthiness of Investment and success of the groundwater development project in Kor Subdistrict, Li District, Lamphun Province. The project's objective is to invest in infrastructure development for agriculture and consumption. The economic development hypothesis aims to address environmental problems (PM2.5 from forest fires) caused by poverty. The worthiness of Investment is evaluated using Social Return on Investment (SROI), with an impacts /investment ratio of 0.41 The success of the project is measured by collecting data through a questionnaire from a population of 184 participants, with 154 respondents. Decision Tree analysis was employed to identify behavioral changes under specified conditions, it was found that 11.04% of the overall population, who benefited from the project, were able to change their behavior and no longer depend on forest products. This research highlights the limitations of rural development that can lead to inefficiency and challenges in achieving success.

Keywords: SROI, Environmental problems, Economic development, Rural, Groundwater Project

1. Introduction

Thailand is facing the problem of PM2.5, which is an environmental issue [1]. It has been proven that high levels of PM2.5, exceeding 5 (µg/m³), have led to increased mortality rates which is a standard set by the WHO. [2], Thailand's average PM2.5 level from 2020-2023 is 22.075 (µg/m³) [3]. In terms of the economy, the economic damage to Thai households in 2019 amounted to 2.173 trillion baht [4]. The main cause of PM2.5 in 2023 is attributed to forest fires, accounting for 69.82% [5].

Ban Kor, Kor Sub-district, Li District, Lamphun Province, is the village that has experienced the highest number of forest fires in the country over the past 22 years. The area surrounding Ban Kor is surrounded by the Mae Ping National Park, experiencing forest fires more than 20 times a year, affecting over 200,000 rai (79,051.38 acres) of forest area annually [6]. The peak period of PM2.5 in Lamphun Province occurs from January to May, which is the period of low agricultural activity in the hot season (March to mid-May) and the harvesting of forest products, such as weaver ant eggs (January to early May), wild vegetables (Pak-wan-pa) (March to May), and puff ball mushrooms (May to June), which generate income for people in the local area. There is a belief that burning can enhance forest productivity and facilitate edible forest product.

The reasons for harvesting products from the forest are due to poverty and land rights disputes in agricultural lands, following the relocation of villagers due to flooding caused by the construction of the Bhumipol Dam in 1963.

The approach mentioned before was initiated by the social sector, specifically the "Ananda Mahidol Foundation Scholarship Recipient Club". Under the assumption that the economy has reached a certain level of

development, the population tends to realize environmental issues. If the population experiences a growing economy, it will be able to support measures to address environmental problems by reducing the original benefits derived from the environment or otherwise. This approach is a compromise and reconciliation between the needs of the population and the environment. To address the environmental issue (The PM2.5 from forest fires caused). This overall concept is referred to the "Ban Kor Sandbox Project."

The Groundwater Development Project is a large-scale agricultural and consumer infrastructure development initiative, encompassing a total of 37 locations, covering an agricultural area of 1,975 rai (780.63 acres) and serving a population of 2,996 people. The main objectives of the project are to increase income from increased agricultural production and improved product quality, and living expenses decrease due to access to clean water for consumption, there will be a reduction in harvesting of forest products. This is because the population can engage in year-round agriculture to generate income. The activities aim to limit forest entry, which is the cause of forest fires, and create long-term benefits that align with the implementation of regulations or restrictions during severe PM2.5 periods.

The research outcomes from the case study will demonstrate the practical resource utilization in development initiatives, effectively mitigating environmental issues as hypothesized in the project's rationale. It supports the argument that innovation can simultaneously reduce pollution and maintain production costs. [7]. This reflects the sustainable economic development or, on the contrary, the economic development in rural areas in a developing country. It is aimed at utilizing existing resources to support the increasing population and eradicate poverty [8]. The higher the utilization of resources for economic development, the higher the environmental degradation [9].

The study results will be demonstrated through 1) evaluations to study the worthiness of economic, social, and environmental viability of investments, and 2) assessment to study the success of the project from the target population's changing behavior trends. This includes the role of intervention in inducing changes in the context of the project's developing rural areas.

2. Concepts and Theories

2.1. Economic Development

The theory used to explain the differences in development levels is "The Stages of Economic Growth" by Rostow [10], which categorizes development into five stages. These stages include: 1) The Traditional Society, where society operates under technological constraints, limiting production functions, despite quantitative changes such as price, population, production, and actual income, as well as new innovations arising from a lack of understanding of the environment, unproductive actions, and a hierarchical social structure. 2) The Preconditions for Take-off, which establishes initial conditions for sustainable industrial development, requiring significant changes in non-industrial sectors, such as transportation infrastructure development, agricultural technological advancements, and increased imports for capital expansion. 3) The Take-off, which stands out for sustainable industrial development, with advancements in technical labor and financial institutions that mobilize resources, propelling technology into all sectors and leading to social modernization, often associated with social, political, and cultural changes, although traditional elements may still exist. 4) The Drive to Maturity, where the economy begins to produce higher-quality goods and services, widely adopting new technologies in various sectors. During this phase, new emerging sectors replace older ones that begin to decline, and growth and expansion occur in leading sectors driven by complex technologies influenced by various factors such as population-resource balance and

income distribution policies. 5) The Age of High Mass Consumption, when society enters a technological age, it must choose additional areas for development. The first direction is enhancing safety, welfare, and leisure through public measures. The next direction is expanding private consumption, including housing and durable goods for mass consumption, and the final direction is seeking increased influence on the global stage [11]. The significant implications of Rostow's stages of development are related to economic changes, social structures, and technological advancements.

Another significant proposal is Lewis [12] dual-sector model, which explains the transfer of labor from the original rural sector, where surplus labor does not contribute to production, to the new industrial sector, which has higher productivity due to wages, profits, and capital investment. The self-sustaining process of growth in the new modern sector and the expansion of employment continue until all surplus labor in the rural sector is absorbed into the new industrial sector. This occurs at a level where agricultural prices increase and the labor-to-land ratio decreases at a balanced level. This represents a structural transformation of the economy from rural agriculture to the urban industrial sector in the new era [11].

2.2. The Agricultural Transformation

In the agricultural sector itself, Timmer (1998) also explains the changes by dividing the levels of agricultural development into: 1) Getting agriculture moving: where the state relies on income from agriculture, utilizes resources to develop infrastructure, conducts research, and applies new technologies to increase returns. Financial resources and labor flow out of the agricultural sector. 2) Agriculture as a contribution to growth: in this phase, there is a clear imbalance between the agricultural and industrial sectors in terms of productivity and income. Differences exist between rural and urban areas, and agricultural prices depend on the market each year. 3) Integrating Agriculture into the macroeconomy: at this stage, the agricultural sector is integrated into the economy through the development of more efficient labor markets and credit systems. This links the urban and rural economies. During this period, the rate of transition from the agricultural sector to the industrial sector accelerates due to higher returns. 4) Agriculture in industrial economies: this phase involves the practice of agriculture in industrialized countries, as the share of agricultural labor decreases and the flow of labor into the industrial sector declines. Economically efficient and affordable food becomes less important. Political problems arise when farmers' incomes are low, and policies to support agricultural prices are implemented to provide social returns from agriculture [13].

2.3. Economic and environment

Environmental degradation increases with growing income up to a certain point, after which environmental quality improves with higher income per capita. This relationship is depicted by an inverted U-shaped curve known as the Environmental Kuznets Curve (EKC), named after Kuznets. The EKC hypothesis suggests a long-term relationship between environmental impact and economic growth. Initially, as economic development accelerates, resource depletion and waste generation increase. However, at higher development levels, a shift towards information-intensive industries, increased environmental awareness, stricter regulations, better technology, and higher environmental expenditures lead to a reduction in environmental degradation. Beyond the EKC turning point, environmental quality starts to improve with rising income [9].

3. Methodology and Result

3.1. The worthiness of Investment

In evaluating impact to study the worthiness of Investment, a structured questionnaire tool will be used with key stakeholders according to Table 1. The participants are selected from the project's stakeholders and those who have been

affected. They will be provided with information regarding the project's progress and activities, starting from March 9th to March 23rd, 2023. The analysis process and outcomes of the Social Return on Investment (SROI) process are as follows:

3.1.1. Identifying key stakeholders

The process of defining the scope and identifying key stakeholders is crucial in assessing the impact and success of a project. This step involves identifying individuals or groups who may benefit from or be affected by the activities and outcomes of the project or organization. This process is related to identifying and understanding needs, concerns, and expectations in the decision-making process of individuals or groups who have influence or interest in the project [14]. This includes both positive and negative impacts on individuals, institutions, organizations, and other social groups, whether intentional or unintentional. The identification of key stakeholders within important boundaries is essential, and the inclusion or separation of stakeholders in the analysis is done comprehensively and logically [15].

Table 1 key stakeholders

Key Stakeholders	Description
Farmers (4)	The number of farmers benefiting from the project: 184 people, covering an area of 386.54 rai. (152.78 acres)
People using water for consumption (4)	Number of people supported by the project: 2,996 people
Kor Subdistrict Municipality Office (1)	Local government unit responsible for Kor Subdistrict, Li District, Lamphun Province. It oversees and develops the livelihoods and living conditions of the population.
Bureau of Groundwater Resources Region 1 (Lampang) (1)	The regional government agency responsible for enforcing laws related to the use of groundwater resources.
Social Sector from the "Ban Kor Sandbox Project" (meeting minutes summary)	Social sector organization addressing PM2.5 issues and forest fire reduction by solving community issues in the local area.

(...)The number of data providers

In defining the developing economy in the context of rural areas, agriculture is a primary income source and a crucial development pathway in this project. The primary beneficiary group of the project are farmers who receive water from the project. This group represents over 80% of the population [16]. The starting point of intervention and impact creation for economic development is based on leveraging existing livelihoods and local understanding within the community. In the case of the project's population, which consists of 184 people, the average agricultural land per person receiving water from the project is 2.10 rai/person (0.83 acres/person) The results demonstrate the surplus labor force of the project. When examining the details in terms of time, the role of groundwater for agriculture is highest during the hot season (mid-February to mid-May). Farmers use groundwater to enhance the quality and productivity of their crops. It is important to note that the increased quantity of production during this period cannot be compared to the crop season. However, considering the higher selling prices during that time due to market demand, it is worthwhile to attract investment from unemployed farmers during that period.

3.1.2. Mapping outcomes

This section helps identify and understand the anticipated outcomes and impacts expected from the project, and it helps explain the causal relationships between components and methods that overall impact [17]. It refers to the Theory of Change (ToC) which is a concept used to measure social impacts. It is a process or method used for planning projects related to proving assumptions and assumptions about the intervention or operation of the project. It focuses on understanding how specific impacts can be achieved and under what conditions, based on empirical evidence and

systematic findings collected from relevant branches or target groups. Additionally, the Logic Model is used, which summarizes the logical connections between inputs, activities, outputs, outcomes, and impacts [18], as shown in Figure 1

areas and developing areas can be reflected through social structures, especially the power in developing the area from key stakeholders and the activities carried out by the local municipality, which is a decentralized structure that can manage its

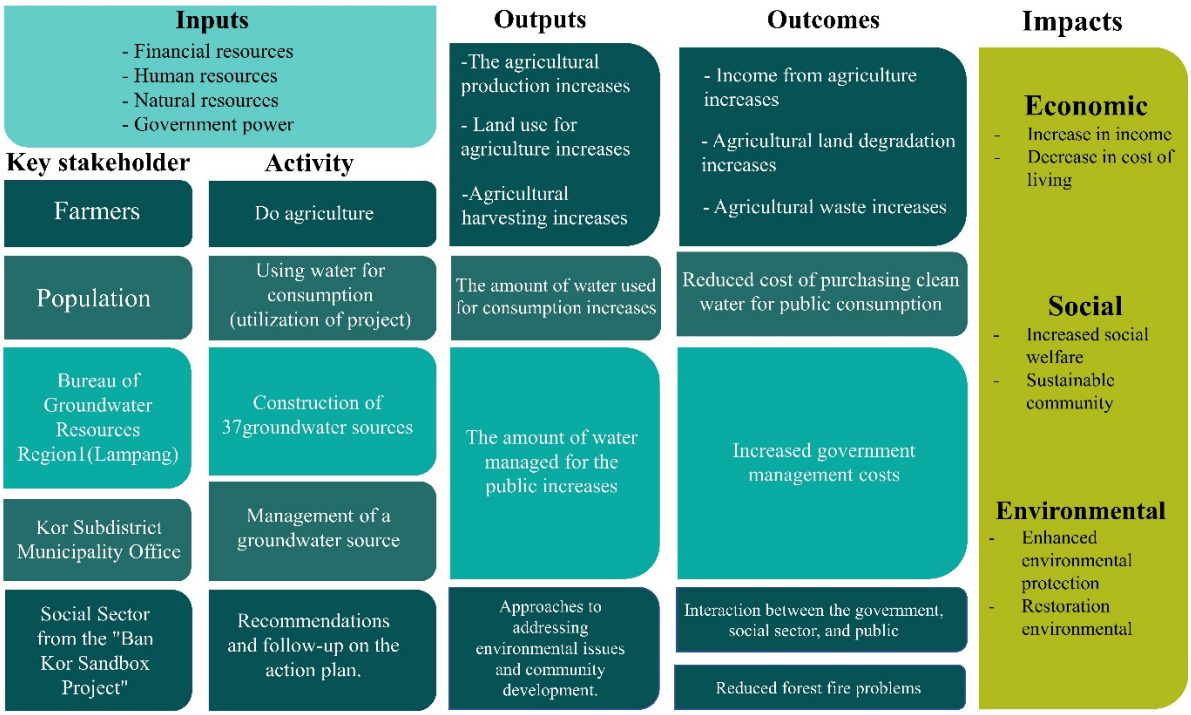

Figure 1. Mapping of research findings from interviews with stakeholders by the researcher

From the mapping outcomes, it is possible to illustrate the context of rural development in the project's association with technology adoption. This involves importing technology through infrastructure investments aimed at economic development from regional sources, facilitated by the key stakeholder, Bureau of Groundwater Resources Region 1 (Lampang), This aligns with the rural economic development approach that requires external investments to create added value production and reduce living costs, resulting in economic impacts that the project aims to achieve. It is expected that technology will help increase efficiency and lead to sustainable agricultural practices in the long run. As for the consumers of groundwater, they benefit from the project by experiencing improved quality of life.

In addition to that, the context of rural

own affairs. The social sector is formed by the collaboration of the community with the aim of addressing issues. Although both organizations are modern democratic social structures, clear and sustainable development cannot be achieved without relying on the existing power structure of centralizing power from the Bureau of Groundwater Resources Region 1 (Lampang), which has the authority to consider activities according to the law and budget for development. This leads to subsequent outcomes and impacts.

3.1.3. Evidencing and valuing outcomes

In this step, which is an important step in the SROI analysis process, data is collected from interviews with key stakeholders, consultations with case study organizations, and other available resources to gather evidence about the outcomes that result from

activities or organizations. Then, the outcomes are evaluated using financial proxies that represent the financial value of these outcomes. This is done in the context of the specific region or country and is expressed in local currency. The value of the outcomes is calculated by multiplying the financial proxy by the number of key stakeholders who experience the outcomes. This process ensures that the outcomes are accurately assessed and provides a comprehensive understanding of the social value created by the activities or organizations [14].

According to the process, the outcomes and impacts of the project or intervention are carefully evaluated, and indicators are selected based on the Theory of Change [19]

In considering the Financial Proxy, which is a measure to determine the value of the outcomes resulting from the project, the process begins by considering the primary data of the key stakeholders through interviews as the main criterion for consideration. Then, market price data (average price) and documents from the government are selected to support the valuation, using criteria of credibility and references that are most relevant to the area during that period. The data will be converted to be consistent with economic evaluation techniques to facilitate decision-making in selecting the value, while avoiding high uncertainty in data and tools. In other words, the evaluation is based on actual value data in the specific area only. For this research, the Financial Proxy used includes: 1) Market price, defined as the use of goods or services of any environmental system that can be freely bought or sold in the market [20], 2) Change in productivity, which is the impact of the project on production and outputs, which can be positive or negative. The increased productivity resulting from these changes can be assessed using market prices [21], 3) Replacement cost, which is the expenditure incurred in replacing assets that have been damaged by the project or activities [22], 4) Defensive expenditure, which is the expenditure incurred by individuals or organizations to protect themselves from potential environmental damage [22], and 5) Opportunity cost, a tool used to assess the value of the best alternative option when making a decision, representing the cost of choosing one option over another [22]. The value of the outcomes can be calculated according to Table 3.

Table 3 Financial proxies and calculated values for Outcomes.

Outcomes	Financial Proxy	value
Increase in agricultural income	The change in agricultural productivity per rai of 189.96 rai and the market price (average price) of each type of agricultural product at 8,841.253 baht per rai in 2023 and 10,494.966 baht per rai in 2025	1,679,484.48 1,993,623.74*
Increase in soil degradation	The replacement cost for restoring soil degradation using an average organic fertilizer price of -1,029.86 baht per rai for 160.21 rai in 2023 and -1,455.86 baht per rai for 189.96 rai in 2025	-164,993.23 -276,555.73*
Increase in agricultural waste	The defensive expenditure for fire prevention for agricultural purposes at 450 baht per rai for 25.25 rai in 2023 and 55 rai in 2025	-11,362.5 -24,750*
Reduced expenditure on purchasing clean drinking water	The market price of clean drinking water at 2.91 baht per liter, with an estimated average consumption of approximately 593,855 liters in 2023 and an estimated consumption of approximately 1,301,955 liters in 2025	1,728,118 3,788,689.05*
Increased public expenditure on water management	The average cost of groundwater management at 2.0176 baht per cubic meter with a volume of 38,795.09 cubic meters in 2023, and the average cost of groundwater	78,273.56 80,750.91*

Outcomes	Financial Proxy	value
	management at 2.044 baht per cubic meter with a volume of 39,503.19 cubic meters in 2025	
Interaction between the government, civil sector, and the public	The opportunity cost of the 10 individuals involved in the guideline development and the 10 individuals benefiting from the workshop, totaling 4 sessions, including the cost of managing and organizing the meeting	98,273
Decrease in forest fires	The defensive expenditure per capita for forest fires at an average of 20.21 baht per person aged 25-60, with a total of 184 individuals participating in the project	3,718.64

* The potential value of benefits, may occur in 2025

In the overall context of Thailand, although the overall development of the country is classified as developing, the actual development varies in different areas [23]. In the context of the research project, it focuses on developing rural areas. However, the current agricultural market development is integrated into the regional economy. This means that it is an "Agriculture in industrial economies" that relies on regional markets to determine prices and cannot be sustained at low agricultural prices to support industrial growth [13]. From the evaluation of the outcomes and the Financial Proxy based on market prices, it is likely to lead to a lower value of agricultural income impacts. Even if farmers choose diversified agricultural crops or invest in infrastructure to increase production, the value is affected.

In terms of environmental development, the evaluation of the environmental-related impacts and their values include increased soil degradation, increased agricultural waste, and reduced forest fires. Overall, these have negative values that impact the economy, with outcomes related to increased agricultural income and reduced expenses in purchasing clean water. These findings are consistent with the concept of the EKC [9], which suggests that resource use and environmental impacts initially increase with income growth due to increased production that is unsustainable in resource consumption. However, there are processes that limit environmental impacts. The positive value of all impacts indicates the effectiveness of the impacts.

3.1.4. Establishing impact

In the process of determining the actual impacts or outcomes of activities, it is important to eliminate biases that may arise or result from other factors [17]. This can be done by limiting and separating the data that is the result of other factors in the analysis [24]. The steps in determining the impacts are linked to using values converted into monetary terms to find the NPV (Net Present Value) of the impacts through discounting, which is a framework determined by the following guidelines [25].

$$NPV = \sum_{t=1}^{n}\left(Financial\ Proxy_j \times Outcome_j\right) \times \frac{1}{Deadwe_j} \times \frac{1}{Displ_j} \times \frac{1}{Attr_j} \times \frac{1}{DropOff_j} \times \frac{1}{(1+r)^t} \quad (1)$$

By defining j as the number of projects, the Financial Proxy is the measure that converts the outcomes into monetary values. It can be assigned to social or environmental outcomes that do not have market prices, following economic valuation techniques. Next is Deadweight ($Deadwe_j$), which measures the outcomes that would occur even if the evaluated activity did not take place. It represents the portion of outcomes that is not a result of the effort or intervention of the project. Displacement($Displ_j$)evaluates whether the outcomes from the project have displaced or substituted other outcomes that would have occurred even without the project's intervention. It is related to understanding the scope of the project's activity, which leads to changes or replacements in the natural outcomes. Attribution (Attr_j) assesses whether the

outcomes can be attributed to the effort or intervention of the organization or other projects. It is related to determining the proportion of outcomes that can be attributed to the project. Finally, Drop-off ($\mathrm{DropOff}_j$) refers to the decline in outcomes over time. The deterioration of outcomes over time is calculated by subtracting a constant percentage from the remaining level of outcomes at the end of each year, with a reduction rate (r) set at 7%. This rate is referenced from a project related to water in the context of water and developing countries [26]. The calculation results are shown in Table 4.

to November 1, 2023. The analysis of the magnitude of the changes was conducted using a Decision Tree to study the role of the project in influencing the behavioral trends of the population. The indicator used to certify that the sample group benefiting from the project would not have environmental impacts ($PM2.5$ from forest fires) is the "cessation of forest product harvesting." The results based on the assumptions expected by the project are shown in Table 5.

According to the study, individuals with the target behavior of entering the forest 1-3 times a year and those who frequently enter the forest account for 66.89% of the total sample group. Additionally, 15.59% of the sample group benefited from the project with the target behavior, and 11.04% were able to improve their behavior without causing any negative impacts. These findings are presented in Table 5.

Table 4 Impact value calculated for outcomes.

Outcomes	Deadweight	Displace-ment	Attribu-tion	Drop-off	value
Increase in agricultural income	0%	0%	0%,20% ,30%	0%	1,654,779.33 1,943,866.77*
Increase in soil degradation	0%	0%	0%	0%	-164,993.23 -181,868.23*
Increase in agricultural waste	0%	0%	0%	0%	-11,475.00 -13,387.50*
Reduced expenditure on purchasing clean drinking water	0%	0%	0%	0%	1,728,118.05 3,788,689.05*
Increased public expenditure on water management	0%	0%	0%	0%	78,272.55 80,750.90*
Interaction between the government, civil sector, and the public	0%	0%	50%	50%	49,136.50
Decrease in forest fires	33%	0%	0%	0%	1,243.89

* The potential value of benefits that may occur in 2025

3.1.4. Calculating the SROI

In evaluating the value of impacts, an Ex-ante approach is used to assess the impacts that occur and anticipate possible scenarios from 2022 to 2027. The values in each year, starting from year 0 to year 5, are as follows: (0) 49,136.50, (1) 3,117,004.29, (2) 2,891,629.26, (3) 4,510,477.60, (4) 4,210,713.87, and (5) 3,933,057.01. The total value is 18,712,018.53 baht. In relation to the project cost of 45,632,640 baht, the SROI value is calculated to be 0.41.

3.2. Project success assessment

From the sample population group that benefited the most (farmers receiving water from the project), the data was collected using a closed-ended questionnaire from October 1

Table 5, which shows the results of behavior changes according to the project's conditions

Original behavior	Utilization of project benefits	Changed behavior
Harvesting in forest 1-3 times/year (N=96) %all=62.34	Used (N=21) %all=13.64	Changed (N=15) %all=9.74
		Not changed (N=6) %all=3.90
	Don't use (N=75) %all=48.70	Changed (N=36) %all=23.38
		Not changed (N=39) %all=25.33

Original behavior	Utilization of project benefits	Changed behavior
Often harvesting in forest (N=7) %all=4.55	Used (N=3) %all=1.95	Changed (N=2) %all=1.3
		Not changed (N=1) %all=0.65
	Don't use (N=4) %all=2.60	Changed (N=2) %all=1.3
		Not changed (N=2) %all=1.3
Never harvesting in forest (N=51) %all=33.12	Used (N=11) %all=7.14	Changed (N=11) %all=7.14
		Not changed (N=0) %all=0
	Don't use (N=40) %all=25.97	Changed (N=38) %all=24.68
		Not changed (N=2) %all=1.3

4. Conclusion

The Groundwater Development Project in Ban Kor, Li District, Lamphun Province, from the assessment and projection of impact values from outcomes since 2022-2027 using SROI, found that an investment of 1 baht will yield a social return on investment of 0.41 baht, which is considered 'unworthy'. This is due to the context of rural and developing areas, including: 1) The economy relies on agriculture with an inefficient labor force ratio when considering the population per agricultural unit area (0.83 acres/person). 2) Rural areas rely on external technology and investment, which involve high investment costs and pose challenges in achieving value. 3) The social structure influences the determination of public infrastructure investment, evident from the project's need to await budget approval from the regional level (Bureau of Groundwater Resources Region 1), while the local level (Kor Subdistrict Municipality Office) and the local population lack sufficient capital to invest independently. 4) Agricultural outputs, which are the main return on investment for the project, are determined by macroeconomic price mechanisms that depress agricultural product prices. 5) The impact from the use of other natural resources, except for the reduced value of forest fires, has a net negative value on the return on investment. This is because creating benefits in one aspect always affects another when calculated in value.

The project success assessment in terms of population size, using Decision Tree, found that there was a behavioral change consistent with the hypothesis of economic development to address environmental problems by only 11.04% from a sample of 154 people out of 184 farmers who benefited economically from the project. Therefore, it can be concluded that the project has a minimal influence on the decision-making ability to change harvesting behavior from the forest, which is a cause of PM2.5 problems.

Acknowledgement

A special thank you to Ananda Mahidol Foundation Scholarship Recipient Club, the sponsor of the scholarship.

Reference

[1] World Health Organization Thailand. The cost of clean air in Thailand [Internet]. 2022 [cited 2024 May 27]. Available from: https://www.who.int/thailand/news/detail/08-06-2022-the-cost-of-clean-air-in-thailand

[2] World Health Organization. WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. Geneva: World Health Organization; 2021.

[3] Pollution Control Department. Report on the pollution situation in Thailand in 2022 [Internet]. 2022 [cited 2024 May 27]. Available from: https://www.pcd.go.th/publication/30311

[4] Puey Ungphakorn Institute for Economic Research. Reducing the cost of living: The short and long of it [Internet]. 2023 [cited 2024 May 27]. Available from: https://www.pier.or.th/briefs/2023/01/

[5] SDG Insights. Policy PM2.5 agriculture [Internet]. 2023 [cited 2024 May 27]. Available from: https://www.sdgmove.com/2023/05/17/sdg-insights-policy-pm2-5-agriculture/

[6] Ban Koh Sandbox. 'Ban Koh Sandbox': A dust solution model that adjusts mushroom growing near homes to create income, helping villagers stop burning forests [Internet]. iGreen; 2024 [cited 2024 May 27]. Available from: https://www.igreenstory.co/ban-koh-sandbox/
[7] Porter M, Van der Linde C. Green and competitive: Ending the stalemate. In: The dynamics of the eco-efficient economy: Environmental regulation and competitive advantage. Vol. 33. 1995. p. 120-34.
[8] Awan AG. Relationship between environment and sustainable economic development: A theoretical approach to environmental problems. Int J Asian Soc Sci. 2013;3(3):741-61.
[9] Dinda S. Environmental Kuznets curve hypothesis: A survey. Ecol Econ. 2004;49(4):431-55.
[10] Rostow WW. The stages of economic growth: A non-communist manifesto. Cambridge: Cambridge University Press; 1990.
[11] Rostow WW. The stages of economic growth. In: Sociological Worlds. Routledge; 2013. p. 130-4.
[12] Lewis WA. Economic development with unlimited supplies of labour. Manchester School Econ Soc Stud. 1954;22(2):139-91.
[13] Timmer CP. The agricultural transformation. In: Handbook of Development Economics. Vol. 1. 1988. p. 275-331.
[14] Clare G, Diprose G, Lee L, Bremer P, Skeaff S, Mirosa M. Measuring the impact of food rescue: A social return on investment analysis. Food Policy. 2023; 117:102454.
[15] Moroń D, Klimowicz M. Using the social return on investment (SROI) as a measure of the effectiveness of social innovation projects implemented under public policies. Soc Enterp J. 2021;17(2):302-27.
[16] Tambon Kor Administration Organization. Economic conditions [Internet]. 2024 [cited 2024 May 27]. Available from: http://www.tambonkor.go.th/page.php?id=5767
[17] Nicholls J, Lawlor E, Neitzert E, Goodspeed T. A guide to social return on investment. 2012.
[18] Rauscher O, Schober C, Millner R. Social impact measurement und social return on investment (SROI)-analysis. New methods of economic evaluation. 2012.
[19] Arvidson M, Lyon F, McKay S, Moro D. The ambitions and challenges of SROI. Third Sect Res Cent Work Pap. 2010; 49:1-22.
[20] Emerton L, Bos E. Value: Counting ecosystems as water infrastructure. IUCN; 2004.
[21] Munasinghe M, Lutz E. Environmental economics and valuation in development decisionmaking. 1992.
[22] Dixon J, Scura L, Carpenter R, Sherman P. Economic analysis of environmental impacts. Routledge; 2013.
[23] Hunter M. The stages of economic development from an opportunity perspective: Rostow extended. Geopolit Hist Int Relat. 2012;4(2):52-80.
[24] Heady L, Keen S. SROI for funders. New Philanthropy Capital; 2010.
[25] Lombardo G, Mazzocchetti A, Rapallo I, Tayser N, Cincotti S. Assessment of the economic and social impact using SROI: An application to sport companies. Sustainability. 2019;11(13):3612.
[26] Buncle A, Daigneault AJ, Holland P, Fink A, Hook S, Manley M. Cost-benefit analysis for natural resource management in the Pacific: a guide. Secretariat of the Pacific Regional Environment Programme; 2016.

Economic Impacts of the Establishment of Special Economic Development Zones in Thailand

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Abstract
This research aims to investigate the impact of the establishment of Special Economic Zones (SEZs) on Gross Provincial Product (GPP) and employment rates in SEZ and non-SEZ areas. The analysis employs panel data, covering all 77 provinces in Thailand on an annual basis from 2010 to 2022. The Panel ARDL (Autoregressive Distributed Lag) econometric model is utilized to examine the long-run impact and equilibrium relationship on GPP and employment rates. The findings reveal that the SEZ policy significantly increases GPP and promotes economic growth in provinces with SEZs compared to provinces without SEZs. However, the long-term impact of SEZs on employment factors is inconclusive. Specifically, SEZs positively influence household savings but negatively affect income levels, both findings being statistically significant. In contrast, investment within SEZs does not show a significant impact. Similarly, the results of the long-run equilibrium relationship of factors affecting employment in non-SEZ provinces have a positive impact on savings and investment, both statistically significant, but the level of savings is not statistically significant. This research emphasizes the importance of government support for labor skill development in SEZ areas to better adapt to the new economic environment and access higher-paying jobs. This research, therefore, focuses on discussing the implications of these findings.
Keywords: Economic Impact, special economic zone (SEZs), Regional Development, Thailand, Panel ARDL Model

1. Introduction

In the past, Thailand's development model emphasized economic growth driven by low-cost factors of production and private sector investment. This approach was pursued until the major economic crisis of 1997, which prompted a shift in aggregate demand and a devaluation of the Thai Baht. The country's economic structure transformed from one based on domestic investment to one heavily reliant on exports. This is evident in the current high export-to-national income ratio of 70% [1], particularly in export-oriented industries that continue to rely on cheap labor from contract manufacturing. However, this economic model carries the risk of resource depletion [2]. Additionally, workers may face wage suppression to maintain employers' and the private sector's competitiveness through low production costs [3].

Recently, Thailand has considerably researched on policies and measures to enhance competitiveness and potentials in foreign investment attraction. This is due to the country's continued reliance on foreign direct investment (FDI) for sustainable economic and industrial growth together [4]. For these reasons, one specific measure has been adopted which is the establishment of Special Economic Zones (SEZs). These zones are known by different names in various territories, such as Special Border Economic Zones [5], but they share common principles: clearly defined geographical boundaries, support for special economic policies, and development systems to promote investment, as well as distinct management from other

areas. This may include special tax laws, dedicated agencies with authority over central government agencies, special regulations for one-stop service, and specific benefits for residents and investors in the zone, as well as the ability to operate under more supportive and legally flexible regulations than the rest of the country [6].

One of the development strategies pursued by the Thai government in recent years has been the establishment of special economic zones (SEZs). This is driven by regional economic linkages, economic expansion, and the impact of other cooperation frameworks such as the Greater Mekong Subregion (GMS). These factors have made it necessary for Thailand to develop investment and trade zones to serve as gateways for future connectivity [3]. Thailand has been promoting SEZ development plans and has had the concept of developing SEZs for local development, especially in border areas, since 2004. Subsequently, on June 19, 2014, the government formulated policies on the establishment of SEZs which are to support Thailand's entry into the ASEAN Economic Community, reduce inequality, stimulate the economy, increase employment, enhance competitiveness with neighboring countries, and create good infrastructure and well-being for the citizens. Mainly, the policies aim to address the problems of illegal migrant workers entering the country's interior, the smuggling of agricultural products from neighboring countries, and congestion at border crossings [7]. The government approved the establishment of five SEZs in the initial phase: Songkhla, Mukdahan, Tak, Trat, and Sa Kaeo (operational since 2015) and five SEZs in the second phase: Narathiwat, Nakhon Phanom, Chiang Rai, Kanchanaburi, and Nong Khai (operational since 2016) [4][6] [8].

While many developed countries use SEZ policies to target economically disadvantaged areas, low-income countries rely on SEZs to promote export diversification and attract foreign investment. It is evident that the establishment of SEZs focused on investment promotion and long-term development in border areas may lead to changes in the characteristics of those provinces, namely the Gross Provincial Product (GPP) and employment in provinces with SEZs. This research is grounded in economic growth theory, which emphasizes the study of GPP, investment, savings, and income. Additionally, it draws upon labor market theory, which highlights the importance of job creation and its contribution to economic growth.

Building on the aforementioned theoretical frameworks, this study employs the Panel ARDL approach to investigate the factors influencing the long-term equilibrium relationship between GPP and employment for provinces with SEZs and non-SEZ provinces in Thailand. This comparative analysis aims to identify the differential effects of SEZs on these economic indicators. The Panel ARDL model is particularly suitable for this study as it can accommodate variables that exhibit stationarity properties of either I(0) or I(1) [9]. This versatility allows the model to circumvent issues arising from non-stationary time series data. Moreover, the Panel ARDL framework enables the incorporation of appropriate lags to capture the dynamic relationships within the specified framework [10].

2. Literature Review

2.1 Studies on Special Economic Zones

Special economic zones (SEZs) can be compared to free trade zones, aiming to stimulate foreign direct investment (FDI), promote rapid export-oriented industrial growth [11], and enhance socio-economic development. A key feature of such schemes is government support in the form of income tax exemptions, zero value-added tax (VAT) on processed goods for export, and no excise tax on luxury goods [12] [13]. Notably, SEZs are designed to create new jobs and improve

infrastructure in the residential areas of SEZ residents. With government support, the growth of existing businesses can attract investment from both domestic and foreign investors. The increased participation of manufacturing in SEZs leads to higher labor demand, stimulating the local labor market [14]. Hence, SEZs are defined as centers for trade and investment, border trade hubs, integrated transportation hubs to support community expansion and new town development [15].

2.2 Economic Impacts of Special Economic Zones

Special economic zones (SEZs) in developing or low-income countries are often established with export promotion policies. The World Bank [16] found that SEZs in developing countries have generally generated higher export values. The regions where SEZs have generated the most exports are Asia and Sub-Saharan Africa.

Furthermore, considering the impact of SEZs on the level of foreign investment in China, Liang [17] found that China's SEZ policy increased foreign investment by 58%, mainly in export-oriented activities. Especially, SEZs often attract foreign investors through the provision of adequate infrastructure and facilities for manufacturing activities, along with tax incentives.

2.3 Impact of Special Economic Zones on the Labor Market

The impact of SEZs on the labor market is crucial for long-term economic development. While many developed countries use SEZ policies in economically disadvantaged areas to target labor development, low-income countries rely on SEZs to promote export diversification, attract foreign investment, and increase local employment. Several studies have addressed the impact of SEZs on the labor market, as follows:

Apichet's [18] study on the economic and social impacts of SEZs found that establishing SEZs in border areas with investment-promoting tax policies attracted both domestic and foreign investors, leading to increased employment rates and reduced income inequality within the SEZ. Moreover, Angkana [19] and Rapeepan [15] noted that the establishment of SEZs has led to higher wage levels for workers in SEZs. Additionally, Aggarwal [20] and Tubmuang [21] stated that SEZs contribute to the development of labor quality through various training formats, such as receiving advanced knowledge and technology, leading to a more skilled workforce.

Therefore, it is evident that the establishment of SEZs attracts more foreign investment to the area, increases production demand, and introduces new knowledge and modern technology. This leads to higher labor demand and attracts highly educated individuals to the area. As mentioned above, the establishment of SEZs may also contribute to higher wages in the area due to increased labor demand; nonetheless, some areas may also face population density issues [18].

3. Methodology

Model and Data.

This research aims to investigate the factors affecting the long-term equilibrium relationship between Gross Provincial Product (GPP) and employment for provinces with SEZs and non-SEZ provinces in Thailand. To compare the results between provinces with and without SEZs, the study utilizes data from 10 provinces with SEZs (Tak, Mukdahan, Sa Kaeo, Trat, Nong Khai,

Nakhon Phanom, Kanchanaburi, Songkhla, Narathiwat, and Chiang Rai) and 67 non-SEZs provinces. The analysis employs secondary data in real terms in panel data format, covering all 77 provinces in Thailand from 2010 to 2022. The variables used to examine the factors affecting GPP and employment are per capita GPP (GPP_{it}) and employment (Emp_{it}). The macroeconomic variables include income level ($Income_{it}$), savings level ($Save_{it}$), unemployment ($Unemp_{it}$), and domestic investment ($Invest_{it}$). The Panel Autoregressive Distributed Lag (Panel ARDL) model is employed to estimate the parameters, which consists of two steps: stationarity tests and the analysis of factors affecting the long-term equilibrium relationship between GPP and employment for provinces with SEZs and non-SEZ provinces in Thailand.

Firstly, the Panel Unit Root Test by Levin, Lin, and Chu (LLC) Test is used to examine the stationarity of each variable to ensure that the data exhibits stationarity at the Level or I(0) and First Difference or I(1) levels. Stationarity tests help mitigate spurious regressions and interpretation problems [9][22][23].

Secondly, once the order of integration of each variable is determined, the Panel ARDL model is employed to analyze the factors affecting the long-term equilibrium relationship between per capita GPP and employment, comparing provinces with and without SEZs. The equations are as follows:

Equation for analyzing factors affecting the long-term impact and equilibrium relationship on GPP per capita

$$\begin{aligned}\Delta GPP_{it}^{in} = {} & \beta_0 + \sum_{i=1}^{p} \beta_{1i} \Delta Unemp_{it-i}^{in} \\ & + \sum_{i=1}^{q} \beta_{2i} \Delta Income_{it-i}^{in} \\ & + \sum_{i=1}^{r} \beta_{3i} \Delta Save_{it-i}^{in} + \sum_{i=1}^{s} \beta_{4i} \Delta Invest_{it-i}^{in} \\ & + \lambda_0 GPP_{it-1}^{in} + \lambda_1 Unemp_{it-1}^{in} \\ & + \lambda_2 Income_{it-1}^{in} + \lambda_3 Save_{it-1}^{in} \\ & + \lambda_4 Invest_{it-1}^{in} + \varepsilon_{it} \end{aligned} \quad (1)$$

$$\begin{aligned}\Delta GPP_{it}^{out} = {} & \beta_0 + \sum_{i=1}^{p} \beta_{1i} \Delta Unemp_{it-i}^{out} \\ & + \sum_{i=1}^{q} \beta_{2i} \Delta Income_{it-i}^{out} \\ & + \sum_{i=1}^{r} \beta_{3i} \Delta Save_{it-i}^{out} + \sum_{i=1}^{s} \beta_{4i} \Delta Invest_{it-i}^{out} \\ & + \lambda_0 GPP_{it-1}^{out} + \lambda_1 Unemp_{it-1}^{out} \\ & + \lambda_2 Income_{it-1}^{out} + \lambda_3 Save_{it-1}^{out} \\ & + \lambda_4 Invest_{it-1}^{out} + \varepsilon_{it} \end{aligned} \quad (2)$$

Equation for analyzing factors affecting the long-term impact and equilibrium relationship on employment

$$\begin{aligned}\Delta EMP_{it}^{in} = {} & \beta_0 + \sum_{i=1}^{p} \beta_{1i} \Delta Income_{it-i}^{in} \\ & + \sum_{i=1}^{q} \beta_{2i} \Delta Save_{it-i}^{in} \\ & + \sum_{i=1}^{r} \beta_{3i} \Delta Invest_{it-i}^{in} + \lambda_0 EMP_{it-1}^{in} \\ & + \lambda_1 Income_{it-1}^{in} + \lambda_2 Save_{it-1}^{in} \\ & + \lambda_3 Invest_{it-1}^{in} + \varepsilon_t \end{aligned} \quad (3)$$

$$\begin{aligned}\Delta EMP_{it}^{out} = {} & \beta_0 + \sum_{i=1}^{p} \beta_{1i} \Delta Income_{it-i}^{out} \\ & + \sum_{i=1}^{q} \beta_{2i} \Delta Save_{it-i}^{out} \\ & + \sum_{i=1}^{r} \beta_{3i} \Delta Invest_{it-i}^{out} + \lambda_0 EMP_{it-1}^{out} \\ & + \lambda_1 Income_{it-1}^{out} + \lambda_2 Save_{it-1}^{out} \\ & + \lambda_3 Invest_{it-1}^{out} + \varepsilon_{it} \end{aligned} \quad (4)$$

The ΔGPP_{it} represents the change in Gross Provincial Product in provinces with and without SEZs, ΔEmp_{it} is the change in Employment in provinces with and without SEZs, $\Delta Unemp_{it}$ demonstrates the change in Unemployment in provinces with and without SEZs, $\Delta Income_{it}$ points out the change in Average income in provinces with and without SEZs, $\Delta Save_{it}$ represents the change in Average savings in provinces with and without SEZs, $\Delta Invest_{it}$ is the change in Investment in provinces with and without SEZs, β is parameters, λ = long-term relationship, t = trend, i = lag, and ε_{it} as the error term. The null hypothesis for the test is $H_0: \lambda_0 = \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = 0$, indicating no long-term relationship. The alternative hypothesis is $H_1: H_0$ rejecting the hypothesis or not being true, which suggests a long-term relationship exists.

4. Research Findings

The empirical analysis of factors affecting the long-term equilibrium

relationship between gross provincial product (GPP) and employment for provinces with SEZs and non-SEZ Provinces in Thailand. To compare the results between provinces with and without SEZs, the empirical analysis is divided into two parts: 1) Stationarity Tests and 2) Analysis of Factors Affecting the Long-Term Equilibrium Relationship between GPP and Employment for Provinces with and without SEZs Using the Panel ARDL Model.

Table 1: Results of Panel Unit Root Test by Levin, Lin and Chu (LLC) Test

Variable	LLC	P-value	Level
$\mathbf{GPP_{it}}$	-17.1314***	0.0000	I(0)
$\mathbf{Emp_{it}}$	-6.4443***	0.0000	I(0)
$\mathbf{Income_{it}}$	-71.8836***	0.0000	I(0)
$\mathbf{Save_{it}}$	-10.9264***	0.0000	I(1)
$\mathbf{Unemp_{it}}$	-14.0184***	0.0000	I(0)
$\mathbf{Invest_{it}}$	-19.957***	0.0000	I(0)

Note: Symbol * Show significant at the 1% level

From Table 1, it shows the results of the stationarity tests for the variables using the Levin, Lin, and Chu (LLC) Test at the level with intercept and trend, level with intercept, and level without intercept and trend. The results indicate that the variables GPP_{it}, Emp_{it}, $Income_{it}$, $Unemp_{it}$ and $Invest_{it}$ reject the null hypothesis, implying that the data is stationary or non-unit root at the I(0) level at the significance levels of 0.01, 0.05, and 0.1.

Conversely, the variable $Save_{it}$ has a Prob. value greater than 0.01 or exceeds the significance level, indicating that the null hypothesis is accepted. This suggests that the data is non-stationary at the I(0) level. Therefore, the data is further tested using the Levin, Lin, and Chu (LLC) Test to determine the higher order of integration of the data. The results show that the order of integration of the data is 1 or I(1), which means that the data is stationary or non-unit root at the first differenced level with intercept and trend, first differenced level with intercept, and first differenced level without intercept and trend. The results indicate that the variable $Save_{it}$ rejects the null hypothesis, implying that the data is stationary or non-unit root at the I(0) level at the significance levels of 0.01, 0.05, and 0.1.

According to the Panel ARDL (Autoregressive Distributed Lag) methodology, data with stationary characteristics at I(0) or I(1) can be used together for calculation. Therefore, after conducting the stationarity tests, the factors affecting long-run equilibrium relationship are analyzed using the Panel ARDL (Autoregressive Distributed Lag) methodology.

This study reports the results of the analysis of panel data using the long-term Panel ARDL (Autoregressive Distributed Lag) model. The model is automatically selected based on the Akaike Information Criterion (AIC). The AIC criterion automatically selects the lag length to be one. The analysis of factors affecting the long-term impact and equilibrium relationship of economic factors is divided into two parts: (1) Analysis of factors affecting the long-term impact and equilibrium relationship on Gross Provincial Product (GPP) per capita and (2) Analysis of factors affecting the long-term impact and equilibrium relationship on employment.

Table 2: Analysis of Factors Affecting the Long-Term Equilibrium Relationship of Gross Provincial Product (GPP) in Provinces with Special Economic Zones (SEZs) Using the Panel ARDL Model (1, 1, 1, 1, 1)

Variable	Coefficient	Std.Error	Prob.
Long Run Equation			
$\mathbf{Income_{it}}$	3.5244***	0.8703	0.0001
$\mathbf{Save_{it}}$	0.8163***	0.1081	0.0000
$\mathbf{Unemp_{it}}$	-1.6332***	0.6130	0.0097
$\mathbf{Invest_{it}}$	6.3818***	1.0032	0.0000

Note: Symbol * Show significant at the 1% level

Based on Table 2, the analysis of factors affecting the long-term impact and equilibrium relationship on Gross Provincial Product (GPP) in provinces with Special Economic Zones (SEZs) reveals that the average income level (Income_{it}) has a long-term estimated coefficient of 3.52. This indicates that a one-unit increase in Income_{it} leads to a 3.52 unit increase in GPP per capita (GPP_{it}) with statistical significance at the 0.01 level. This positive and statistically significant impact on GPP_{it} stems from the increase in Income_{it}, which drives the GPP_{it}, and ultimately enhances the quality of life for residents through improved access to education and healthcare. Furthermore, the average savings level (Save_{it}) in provinces with SEZs exhibits a long-term estimated coefficient of 0.81. This implies that a one-unit increase in Save_{it} in these provinces results in a 0.81-unit increase in GPP_{it}, with statistical significance at the 0.01 level. This elevated Save_{it} reflects the improved quality of life for residents in SEZs. Additionally, the unemployment rate (Unemp_{it}) shows a long-term estimated coefficient of -1.63. This indicates that a one-unit increase in Unemp_{it} in provinces with SEZs leads to a 1.63-unit decrease in GPP_{it}, with statistical significance at the 0.01 level. This negative and statistically significant impact on GPP_{it} underscores the importance of reducing Unemp_{it} to promote economic growth. More importantly, the investment level (Invest_{it}) in provinces with SEZs presents a long-term estimated coefficient of 6.38. This signifies that a one-unit increase in Invest_{it} results in a 6.38-unit increase in GPP_{it}, with statistical significance at the 0.01 level. This highlights the crucial role of Invest_{it} in driving economic growth. Therefore, investment-promoting policies are essential for enhancing GPP_{it} and investment, which serve as a key strategy for fostering economic development in SEZs, paving the way for sustainable economic progress. By implementing policies that support workforce development, the government can potentially contribute to lower unemployment rates and higher income levels.

Table 3 : Analysis of Factors Affecting the Long-Term Equilibrium Relationship of Gross Provincial Product (GPP) in Provinces without Special Economic Zones (SEZs) Using the Panel ARDL Model (1, 1, 1, 1, 1)

Variable	Coefficient	Std.Error	Prob.
	Long Run Equation		
Income_{it}	1.1109***	0.3329	0.0009
Save_{it}	0.2410***	0.0509	0.0000
Unemp_{it}	-1.2055***	0.2453	0.0000
Invest_{it}	-0.2330*	0.1407	0.0985

Note: Symbol * Show significant at the 1% level

Table 3 presents the analysis of the factors affecting the long-term impact and equilibrium relationship of Gross Provincial Product (GPP) in provinces without Special Economic Zones (SEZs). The results indicate that the average income level (Income_{it}) has a long-term estimated coefficient of 1.11. This suggests that a one-unit increase in Income_{it} in non-SEZ provinces leads to a 1.11-unit increase in GPP per capita (GPP_{it}), with statistical significance at the 0.01 level. The positive impact on GPP_{it} stems from the increase in Income_{it}, which boosts household consumption. Furthermore, the average savings level (Save_{it}) exhibits a long-term estimated coefficient of 0.24. This implies that a one-unit increase in Save_{it} in non-SEZ provinces results in a 0.24-unit increase in GPP_{it}, with statistical significance at the 0.01 level. The accumulation of savings reflects increased income, economic growth, and reduced long-term economic risks. On the other hand, the unemployment rate (Unemp_{it}) demonstrates a long-term estimated coefficient of -1.2. This indicates that a one-unit increase in Unemp_{it} leads to a 1.2-unit decrease in GPP_{it}, with statistical significance at the 0.01 level. This negative impact on GPP_{it} highlights the detrimental

effects of unemployment. Higher $Unemp_{it}$ leads to underutilized labor resources, reduced output, and economic contraction. Likewise, the investment level ($Invest_{it}$) presents a long-term estimated coefficient of -0.23. This signifies that a one-unit increase in $Invest_{it}$ in non-SEZ provinces results in a 0.23-unit decrease in GPP_{it}, with statistical significance at the 0.10 level. This finding suggests that $Invest_{it}$ may have a negative impact on GPP_{it}. This could be attributed to inefficient resource utilization or excessive $Invest_{it}$ without proper planning, potentially leading to future debt problems. Nonetheless, investment requires careful planning and the development of modern infrastructure to meet market demands. Implementing these policies will contribute to the sustainable growth of the economy in provinces without SEZs.

The findings of the study on the factors affecting the long-term equilibrium relationship of gross provincial product (GPP) in provinces indicate that the establishment of special economic zones (SEZs) in Thailand has a significantly positive impact on per capita GPP compared to provinces without SEZs. This is attributed to the increase in income, savings, and investment in provinces with SEZs, leading to economic growth. SEZs have policies that promote investment, tax incentives, and other benefits. Additionally, an increase in unemployment has a negative impact on GPP. Therefore, the establishment of SEZs should be accompanied by workforce development policies. In summary, the overall picture suggests that the presence of SEZs is a significant factor in driving sustainable and robust GPP growth.

Table 4: Analysis of Factors Affecting the Long-Term Equilibrium Relationship of Employment in Provinces with Special Economic Zones (SEZs) Using the Panel ARDL Model (1, 1, 1, 1)

Variable	Coefficient	Std.Error	Prob.
Long Run Equation			
$Income_{it}$	-4.9026***	1.4932	0.0015
$Save_{it}$	5.1920***	1.7006	0.0031
$Invest_{it}$	3.5692	2.2435	0.1157

Note: Symbol * Show significant at the 1% level

Table 4 illustrates the analysis of the factors affecting long-term impact and equilibrium relationship of employment (Emp_{it}) in provinces with Special Economic Zones (SEZs). The results indicate that the average income level ($Income_{it}$) has a long-term estimated coefficient of -4.9. This suggests that a one-unit increase in $Income_{it}$ leads to a 4.9-unit decrease in Emp_{it}, with statistical significance at the 0.01 level. The negative impact of $Income_{it}$ on Emp_{it} stems from the potential increase in labor costs associated with higher income levels, which may induce businesses to reduce hiring to maintain profitability. Conversely, the average savings level ($Save_{it}$) exhibits a long-term estimated coefficient of 5.19. This implies that a one-unit increase in $Save_{it}$ results in a 5.19-unit increase in Emp_{it}, with statistical significance at the 0.01 level. The positive impact of $Save_{it}$ on Emp_{it} is attributed to the increased availability of capital for investment in new businesses or the expansion of existing ones, leading to job creation. Additionally, the investment level ($Invest_{it}$) in SEZs presents a long-term estimated coefficient of 3.56. This signifies that a one-unit increase in $Invest_{it}$ would result in a 3.5-unit increase in Emp_{it}. However, the Prob. value of 0.1157, which exceeds the statistical significance level of 0.10, indicates that the relationship is not statistically significant. This contradicts

economic theory, which indicates that investment should be a key factor in driving employment growth. In this case, it is possible that investment in SEZs has not yet reached a level where it can generate a clear positive impact on employment.

Table 5: Analysis of Factors Affecting the Long-Term Equilibrium Relationship of Employment in Provinces without Special Economic Zones (SEZs) Using the Panel ARDL Model (1, 1, 1, 1)

Variable	Coefficient	Std.Error	Prob.
Long Run Equation			
$\mathbf{Income_{it}}$	-0.4104	0.2618	0.1176
$\mathbf{Save_{it}}$	0.1325**	0.0652	0.0426
$\mathbf{Invest_{it}}$	0.5857*	0.3507	0.0955

Note: Symbol * Show significant at the 1% level

The results of the analysis of factors affecting the long-term equilibrium relationship of employment (Emp_{it}) in provinces without Special Economic Zones (SEZs) indicate that income level ($Income_{it}$) has a long-run coefficient estimate of -0.41. This suggests that a one-unit increase in $Income_{it}$ would lead to a 0.4-unit decrease in employment. However, the Prob. value of 0.1176, which exceeds the statistical significance level of 0.10, implies that the relationship is not statistically significant. This could be because changes in income may have a relatively small impact on employment, making the observed changes in the income variable insufficient to influence employment. In contrast, the savings level ($Save_{it}$) of provinces without SEZs exhibits a statistically significant positive impact on employment in the long run. The long-run coefficient estimate is 0.13, indicating that a one-unit increase in savings level would lead to a 0.13-unit increase in employment. This is consistent with economic theory, which posits that higher savings levels provide more capital for investment, fueling economic growth and subsequently driving employment expansion. Similarly, investment ($Invest_{it}$) also demonstrates a statistically significant positive impact on employment in the long run. The long-run coefficient estimate is 0.58, suggesting that a one-unit increase in investment would lead to a 0.58-unit increase in Emp_{it}. This aligns with economic principles, as increased investment often leads to business expansion, creating new employment opportunities.

The findings of the study on factors affecting the long-term equilibrium relationship of employment in provinces with and without SEZs are inconclusive. While savings have a positive impact on employment, income has a statistically significant negative effect. Investment, on the other hand, does not exhibit a statistically significant impact. These results contradict the theoretical expectation that SEZs would have a positive impact on employment. Similarly, the results for provinces without SEZs show a statistically significant positive impact for both savings and investment, but the impact of savings is not statistically significant. This also deviates from economic theory, as investment is typically considered a key driver of employment growth.

The inconclusive nature of the findings suggests that the factors considered in the study may not be sufficient to fully capture the complex dynamics influencing the long-term equilibrium relationship of employment in both SEZs and non-SEZ provinces. Further research is warranted to explore additional factors and their potential interactions to gain a more comprehensive understanding of the determinants of employment (Emp_{it}) in these settings.

5. Research Conclusion

This research aims to investigate the factors affecting the long-term equilibrium relationship between Gross Provincial Product and employment for provinces with SEZs and non-SEZ provinces in Thailand. To compare the results between provinces with and without SEZs.

The research findings reveal that the long-term impact of SEZs on GPP factors indicates that income level, savings level, and investment have a statistically significant positive impact on GPP in provinces with SEZs. This positive relationship indicates that these factors stimulate economic growth and enhance the quality of life for residents in SEZ areas. Additionally, unemployment exerts a statistically significant negative impact on per capita GPP. Therefore, reducing unemployment is crucial for boosting per capita GPP. In contrast, the analysis of factors affecting GPP in non-SEZs provinces shows that only income level and savings level have a statistically significant positive impact on per capita GPP. This suggests that adequate financial reserves mitigate long-term economic risks. Conversely, unemployment has a statistically significant negative impact on per capita GPP, as higher unemployment levels lead to economic contraction. Interestingly, investment exhibits a statistically significant negative impact on per capita GPP in non-SEZ provinces. While investment typically drives economic growth, this counterintuitive finding may be attributed to unplanned investments that could lead to future debt obligations. Overall, the study demonstrates that the presence of SEZs has a more positive impact on GPP compared to non-SEZ provinces. This is likely due to the policies implemented in SEZs to promote investment and provide tax incentives, such as import tax reductions for raw materials and machinery used in manufacturing. Additionally, SEZs often implement workforce development policies that support training and skill enhancement for local workers. These factors contribute to the sustainable growth of GPP in provinces with SEZs.

The analysis of employment factors in SEZs reveals inconclusive results. Income level has a statistically significant negative impact on employment, suggesting that rising income levels may lead to higher labor costs, potentially prompting businesses to reduce hiring. In contrast, savings level exhibits a statistically significant positive impact on employment, as increased savings facilitate business expansion and job creation. However, investment does not show a statistically significant impact on employment in SEZs, which contradicts economic theory. This may be because some investments in SEZs have not yet reached a level where they can generate clear employment outcomes. The analysis of employment factors in non-SEZ provinces indicates that income level has no statistically significant impact on employment. This suggests that income level does not influence employment in these provinces. Interestingly, both savings level and investment have a statistically significant positive impact on employment in non-SEZ provinces. Higher savings levels provide capital for new businesses, leading to increased employment opportunities. In conclusion, the findings on the long-term equilibrium relationship of employment (Emp_{it}) in provinces with and without SEZs are inconclusive. This may be due to the limited scope of factors considered in the study. Further research is warranted to explore additional factors and their interactions to gain a more comprehensive understanding of the determinants of employment (Emp_{it}) in both SEZs and non-SEZ provinces.

Recommendations for Future Research

From the research findings, they reveal a clear distinction in the economic factors influencing GPP in provinces with and without Special Economic Zones (SEZs). SEZs demonstrate a more positive impact on GPP compared to non-SEZ provinces. Interestingly, in the case of non-SEZ provinces, investment exhibits a negative impact on GPP, warranting further investigation into the underlying causes.

Future research should also delve deeper into the factors affecting employment in both SEZ and non-SEZ provinces. This includes considering additional factors such as Foreign Direct Investment (FDI Inflow),

Infrastructure Development Cost, Number of Companies in SEZs and Non-SEZs, Wage, and Training and Skill Development Expenditure. Additionally, collecting data over a longer period would enhance the accuracy of the findings.

Acknowledgement

I would like to extend my sincere appreciation to Assistant Professor Dr. Warattaya Chinnakum for their invaluable guidance and unwavering support throughout this research project.

Reference

[1] International Institute for Trade and Development. (2010). Creative economy and the development of Thailand. Retrieved March 10, 2023, from https://www.itd.or.th/itd-data-center/research-report_creative-economy-development/

[2] Panyawat, J., & Pitsamai, J. (2018). The impacts of Kanchanaburi Special Economic Zone policy on local people in Baankao Sub-district. Economics and Public Policy Journal, 9(18), 72-90.

[3] National Economic and Social Development Board, Office of the Strategy and Area Development Planning. (2016). Thailand's special economic zones. Retrieved March 10, 2023, from https://data.opendevelopmentmekong.net/th/library_record/thailands-special-economic-zones-/resource/18abd671-c2b7-4bed-85fe-37ca7d89adcb

[4] Office of the Board of Investment. (2014). Investment promotion journal, Volume 25, Issue 11. Retrieved March 10, 2023, from https://data.opendevelopmentmekong.net/th/library_record/25-11

[5] Somsak, C. (2014). Macroeconomic factors influencing foreign direct investment in Thailand. Journal of Economics and Management Strategy, 1(1), 55-65.

[6] International Institute for Trade and Development (Public Organization). (2017). Guidelines and measures for the development of special economic zones along Thailand's border areas. Retrieved March 10, 2023, from https://data.opendevelopmentmekong.net/th/library_record/guideline-and-policy-measure-to-develop-and-form-thailands-special-economic-zones

[7] Open Development Mekong. (2018). Special economic zones. Retrieved March 10, 2023, from https://thailand.opendevelopmentmekong.net/th/topics/special-economic-zones/

[8] Wattana, S. (2017). Development of Thailand's border special economic zones: Feasibility and limitations. Retrieved March 15, 2023, from https://socanth.tu.ac.th/wp-content/uploads/2018/02/JSA-36-1-wattana.pdf

[9] Pesaran, M. H., Shin, Y., & Smith, R. J. (2001). Bounds testing approaches to the analysis of level relationships. Journal of Applied Econometrics, 16, 289-326.

[10] Bahmani-Oskooee, & Goswami, G. (2003). A disaggregated approach to the Japanese trade. Journal of Applied Economics. (In press).

[11] Rawat, V. B., Bhushan, M. B., & Surepally, S. (2010). The impact of special economic zones in India: A case study of Polepally SEZ. International Land Coalition.

[12] Aritenang, A. F., & Chandramidi, A. N. (2020). The impact of special economic zones and government intervention on firm productivity: The case of Batam, Indonesia. Bulletin of Indonesian Economic Studies, 56(2), 225-249.

[13] Ambroziak, A. A. (2016). Income tax exemption as a regional state aid in special economic zones and its impact upon development of Polish districts. Oeconomia Copernicana, 7(2), 245-267.

[14] Ambroziak, A. A., & Hartwell, C. A. (2018). The impact of investments in special economic zones on regional development: The case of Poland. Regional Studies, 52(10), 1322-1331.

[15] Chantran, R., & Colleagues. (2018). The impact on people from the establishment of the Songkhla Special Economic Zone. Proceedings of the 1st National Conference on Humanities and Social Sciences.
[16] The World Bank. (2008). Special economic zones: Performance, lessons learned, and implications for zone development. FIAS Research Centre.
[17] Liang, Z. (1999). Foreign investment, economic growth, and temporary migration: The case of Shenzhen Special Economic Zone, China. Development and Society, 28(1), 115-137.
[18] Apichet, T. (2019). Socio-cultural impacts of the Special Economic Zone in Sa Kaeo province.
[19] Tasaena, A., Kantha, T., & Thongaem, M. (2022). Quality of life of Thai workers in Tak Special Economic Zone. Journal of Research and Development Institute, Bansomdejchaopraya Rajabhat University, 6(1). ISSN 2774-1176 (Online).
[20] Aggarwal, A. (2007). Impact of special economic zones on employment, poverty and human development (No. 194). Working paper.
[21] Tubmuang, A. (2021). Social and cultural impacts of Sa Kaeo Special Economic Zone. Journal of Social Development, 23(1), 143-162.
[22] Kasarin, B. (2011). Analysis of factors affecting the rate of return of securities in the tourism and recreation sector of the Stock Exchange of Thailand using ARDL method.
[23] Murthy, V. N. R., & Okunade, A. A. (2016). Determinants of US health expenditure: Evidence from autoregressive distributed lag (ARDL) approach to cointegration. Economic Modelling, 59, 67-73.

A Historical Perspective on Cinchona Cultivation in Nilgiris and its impact on Global Health Care

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Abstract

This paper delves into the medicinal plant cinchona, renowned for its use in curing malarial fever. In the 19th and 20th centuries, the severity of the disease and the plant's medicinal significance led to the cultivation of cinchona becoming a primary governmental task. Regions with favorable climates were chosen, and cultivation commenced in Nilgiris. A substantial sum of money was invested in its development. The quinine medicine produced in Nilgiris was exported to numerous provinces and all malaria-affected countries globally. Official records confirm that the cultivation of the cinchona plant began in 1859, and its journey continued until 1990. Notably, the drug quinine derived from the cinchona plant continues to play a crucial role in medicine today. This article provides a concise account of the introduction of the cinchona plant, its cultivation, governmental initiatives, expenses, and distribution.

Keywords: Cinchona, Distribution, Expenditure, Malaria, Quinine

Introduction

The Cinchona Plantations in India

The Cinchona tree, a South American native, was popularly known as Cinchona.[1] Its bark, first introduced into Europe in 1640, derives its name from Countess Chinchon, the wife of the Peruvian Viceroy, who was cured of a fever by this bark in 1638.[2]

This tree, cultivated for its bark, possesses potent medicinal properties, making it a cure for various diseases, notably malarial fever. Its first recorded mention was by Sebastiano Bado, an Italian physician, in 1663.[3]

Malaria, a formidable adversary, was one of the world's leading causes of death in the 19th and 20th centuries. In those early days, when a cure for this mosquito-borne disease was yet to be found, quinine, discovered in 1820 from the cinchona tree, emerged as a game-changer. Its use as a cure for malaria led to significant health improvements in malarial fever sufferers. Recognizing its potential, the British government took strategic steps, selecting various countries to cultivate the tree in suitable climates. This led to the tree being grown in India in the 1850s, and the production of a drug called quinine from it, which was then exported to all malaria-affected areas of the world. The advent of cinchona and quinine was a turning point in the history of India, sparking economic and social changes that reverberate to this day.

In 1852, the Governor-General of India, Dalhousie, wrote a letter to the Court of Directors of the East India Company to supply seeds and young plants of the best species of cinchona-yielding quinine.[4] The Cinchona tree was planted in the Nilgiris in 1859. The government appointed officers Dr Cheghorn and Mr Mclvor, who played a crucial role in the project. They were tasked with getting the necessary seeds from South America and overseeing the successful implementation of the project.[5] Their efforts were not without challenges, as they had to navigate the complexities of international seed transportation and ensure the survival of the delicate Cinchona plants in the Indian climate. The British government used the prisoners in the jail under its administration to cultivate these trees. Jails were also set up to accommodate them. Especially in the Nilgiri Hills alone, prisons have been set up in three places, and the Cinchona tree planting project has been successfully implemented.[6] Due to the severe impact of the disease, malaria fever spread in different countries around the world, and the need for anti-malarial medicine increased in all countries. Malaria's extensive distribution across tropical and subtropical regions necessitates a detailed geo-graphical distribution, as illustrated in the accompanying chart.

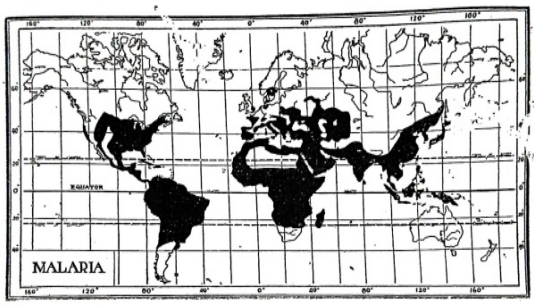


FIG. 1.—Geographical distribution of malaria.

Source: Stitt. E. R, The Diagnostics and treatment of tropical disease, P.Blakiston son, 1922, p.3.

However, due to the shortage of medicine, the government focused more on improving the yield of the cinchona tree and making malaria medicine from it. Thereby, the yield of trees was increased, a quinine factory was set up, and medicine was produced in large quantities. Also, quinine drugs manufactured in India were exported to all malaria-affected countries worldwide. So the government also got a good income.

Methodology

The study utilizes standard historical research methods, including careful collection, authenticity validation, content analysis, and interpretation of primary and secondary sources. So far as secondary sources are concern, sources such as published books, articles in journals have been used. In case of primary sources, sources from Administrative Reports of Madras Presidency, Public Department, Judicial Department, Revenue Department, Development Department, Cinchona Department.

Economic Significance of Cinchona Cultivation in Western Ghats

The Western Ghats, a unique ecosystem, played a significant role in the economic growth of the Indian communities of the Nilgiri hills. Recognizing its potential, Mcivor hoped to offer the Indian community seeds at a low price and of as good quality as can be produced in any part of the world. This knowledge, he believed, was the key to successful acclimatization, as he

explained in the report for 1855-1856. According to official records, the total expenditure of cinchona cultivation was 70,000 pounds up to 1872.[7] Four kinds of inferior bark are available in the market. It was much cheaper, like 15 dollars, in those days. The export of cinchona bark led to a significant boost in the economic condition. The total expenditure on the Government cinchona plantations from the commencement in 1860 up to the end of March last is stated to have amounted to rupees 6,17,194. The number of plants on 9 May 1861, which could be considered the start of cultivation, was as follows:

Cinchona Succirubra	**507**
Cinchona Calisaya	**4**
Cinchona Nitida	**392**
Cinchona Micrantha	**211**
Cinchona Peruviana	**14**
Total no	**1128**

[1}Table

Source: Madras Presidency Administrative Report 1862-1863

On 31 December 1861, the number of these plants was carefully increased to 8,613. This meticulous management continued on 30 April 1862, when they were further increased to 31,495. By 31 December of the same year, the total number of plants was 1,17,706, not including 1,619, distributed to the public, which later considerably exceeded the original stock. On 30 April 1863, the number of plants had increased to 1,57,704. At this date, 2,628 plants had been distributed to the public, and 41,397 plants were permanently planted in the government plantations, covering about 85 acres of land. The Cinchona Plantation was transferred on 18 June 1883 from the forest department. 13,15,446 plants were on the government cinchona estates on 31 March 1884. At the close of the year 1911, the total area under cultivation in the three estates was 1,193.15 acres of cinchona.[8]

Financial status and maintenance of the Indian plantations in the 1880s

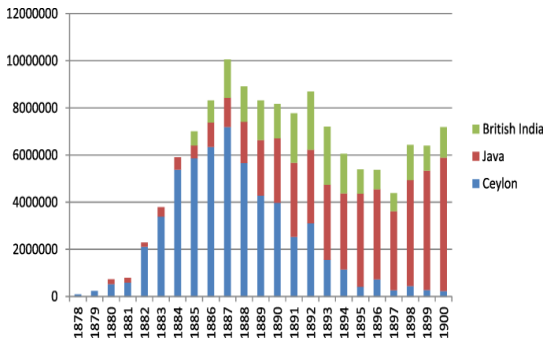
The annual report of the 1880 Secretary of State for India reveals that the plantation has been diligently maintained and has realized a net profit of RS 3, 27,589. However, there is a charge for interest on the balance of capital outlay. Looking ahead, it's important to note that as per the present report and information from the late Cinchona committee, the capital charge against the plantations at the end of 1878–79 was not more than about RS 2 34,000. By the end of the current year, this charge will have been completely cleared off, paving the way for a more prosperous future for the plantation**.[9]**

Indian Quinine production and its impact on global health care

The scale of Indian quinine production, combined with its affordable price, positions it as a significant export commodity, given its role in combating fevers and diseases.[10] The demand for quinine, sourced from the cinchona tree, remains robust. Notably, Chinese prisoners, despite their circumstances, have reportedly shown exceptional dedication in establishing cinchona plantations in substantial numbers. While profit may be the primary motivation for the large-scale cultivation of cinchona across the Nilgiris, official

statements also express sympathy for those affected by poverty.[11]

India, with its potential for increased cinchona plantations and quinine production, holds a promising future. However, the current annual consumption, which has been a little over 200,000 pounds, is far from sufficient. There is a pressing need for more clarity between the requirements and the demand for quinine in India. The two leading causes are prejudice, ignorance, and apathy on the part of the patients, and the high price of quinine.[12] These challenges are not to be taken lightly. Despite these, India is ready to extend its cinchona plantations and produce more quinine. The difficulties in the areas suitable for growing the best quinine-producing bark are being addressed. The total sales of quinine at the Naduvattam factory have risen from 234ib, and it is also being exported to other countries. The plantations established in India and Ceylon have the potential to supply London with adequate amounts of bark (hence quinine).
According to the "League of Nations" Malaria Committee report, the world's annual production of cinchona bark is 11,666,000 kg 10,000,000, with the majority coming from the Dutch East Indies and slightly more than half from British India[13]



Source: Dethloff & Chinin, Studies in history and philosophy of biological and biomedical sciences, University of Utrecht, ISBN-13698486, p.28

Cinchona bark exported in kilogram in the British and Dutch empires 1878-1900.[14]

Well-functioning administration and government control of the Cinchona sector

A separate department was set up for Cinchona, and its entire administration was supervised. In the 19th and 20th centuries, the sector's administration was well-functioning. All the administrative activities of the Cinchona sector, which was not just under the control, but the direct control of the government, were adequately monitored, and monthly and annual management reports were submitted to the government and verified.[15] Among them, each place selected for cultivation, their climatic changes, and medicinal products manufactured and exported were given special attention and handed over as government documents.

Historical developments in malaria control and public health activities

In the 1920s, Annual National and International Conferences on Malaria were held at various places, and the International Malaria Congress was held in places like Singapore, Mumbai, and Kolkata. The officials, enriched by a wealth of trainings and recommendations, were equipped with the knowledge to combat malaria.[16] Also, a regional Malariaologist was appointed, and disease severity and

activities were monitored under their control.

Quinine drug's development history

The government appointed experts to prepare the quinine drug. Government officials appointed for that purpose were called Quinologists. They received all the privileges of the government, and special attention was paid to their administration, ensuring that every aspect of the drug preparation was meticulously overseen.[17] Mr.Hooper, the government quinoxologist, has prepared a liquid extract of cinchona from bark, which the director considers excellent in every respect and thinks will be a cheaper drug than any that has yet been made. Mr. Hooper sent several species of bark to the colonial and Indian Exhibition.[18]

British quinine factory history

The British government's initiative to set up quinine factories in India, such as those in West Bengal and the Nilgiris, was a significant undertaking. These factories, under direct government control, appointed employees to various posts, with the Manufacturing Chemist playing a crucial role in the appointment of multiple officers and the enforcement of a well-organized administration.[19]

Convict labor's impact

In 1864 W. G. Mcivor superintendent of cinchona plantations and architect of the Government botanical gardens, asked the British Government to provide 500 convicts for developing the plantations because local workers too lethargic. The first convicts arrived in 1865 the Straits Settlements of Singapore, Malacca, Dinding and Penang, a group of British territories in South East Asia. Finally the convicts started the plantation.[20] Under the Indian factories Act for 1942 the Director of industries and commerce official report mentioned Government quinine factory at Naduvattam (Nilgiri) total workers are 52 (50 mens 2 Women).[21] Labour force of the government cinchona plantations and government quinine factory at Naduvattam and of the government cinchona plantations Dodabetta who number about 1,200.[22] Not only convicted prisoners from Naduvattam sub jail worked in the plantation. But local workers also worked under this cinchona plantations. In the manufacturing field also the British officers give much importance to the local people. So the economic level of the society was increased.[23]

In the economic development, the occupation like manufacturing quina medicine, tea and coffee plantations, vegetations, cattle rearing plays an important role. These all are successfully done by the Chinese convicts and the local people. The economic condition of the local people was highly developed by the sub jail.[24]

The Historical quinine tablet distribution

SALES OF QUININE SULPHATE AND CINCHONA FEBRIFUGE AND TABLETS IN INDIAN STATES FROM 1929 to 1935

Years		192919 30	1930 1931	193119 32	1932 1933	193319 34	193419 35
mysore	Q	839	579		106	123	310
	C	5	457		1023	1020	1029
	T	257	317				
Hyderabad	Q	400	450	165	213	167	120
	C	690	300	200	360	110	325
	T					10	6
Baroda	Q	1100	1100	1220	1560	810	2260
	C	70	20		50	44	
Travancore	Q	800	800	800	800	600	401
	C	800	800	800	800	200	
	T					200	200
cochin	Q	270	600		60		
	C	60		110			

[2]Table

Source: (G.O No 59, Dated 16th January 1936, Development Department)

Government efforts to distribute quinine tablets during the 1930s.

In the 1930s, as the severity of the disease increased, the government provided quinine tablets free to the people. A key part of this initiative was the appointment of officers who played a crucial role in the effective implementation of the scheme. These officers ensured that the tablets were specially prepared, packed, and distributed to the people. The government also used advertisements to inform the public about this important effort.[25]

Newspapers:

English: The Hindu,The Mail, The Indian Express
Tamil: Dhinamani, Dhinarasi
Telugu: Andhra prabha
Kannada: Samuktha Karnataka

Journals: 1.The Antiseptic Madras 2. The Indian Medical Gazetteer (Calcutta) 3.The Statesman (Calcutta) 4. The illustrated weekly of India (Bombay) 5. The Times of Indian (Bombay) 6. Indian Journal of Medical Science (Bombay) 7.Medical Review of Reviews (Delhi)
8. Nav Bharat Times 9. Hindustan 10. Navabharat 11. Municipal Engineering (Bombay).[26]

Conclusion

The introduction of the cinchona tree by the British in the Nilgiris to control malaria had a huge socio-economic impact. Several lakhs of rupees were spent to increase its development. All the activities were strictly controlled by the government. A Cinchona department was set up to monitor it and all the information was handed over to the government as an annual report. The quinine drug produced in the Nilgiris was exported to all malaria-affected places in the world. It is noteworthy that its role in the field of medicine remains essential till date.

References

[1] Administrative Report of Madras Presidency (1863-1864), Chief Secretary of Government, Fort Saint George, Madras, pp.28-29

[2] E.R.Stitt, The Diagnostics and Treatment of Tropical Diseases, Maple press company, York, U.S.A, 1922, p.46

[3] Meyer, Christian . G, Editorial: Gintonic revisited, Tropical medicine international health, 2004, p.1239.

[4] Letter from Governor General Dalhousie to East India Company , Fort William, 27 march 1852.

[5] G.O No.1072, Dated 15th July 1859, (Seeds and Plants), Public Department.

[6] G.O No.1619, Dated 6th September 1864, (Cinchona Plantation), Judicial Department.

[7] Lardner Gibbon, Exploration of the valley of the amazon, Volume II, pp.146-147

[8] Madras Presidency Administrative Report 1911-1912, p.160

[9] G.O No.278,Dated 4th March 1880(Annual Report) Revenue Department

[10] Dethloff & Chinin, Studies in history and philosophy of biological and biomedical sciences, University of Utrecht, ISBN-13698486, p.28

[11] Deccan chronicle , oct 11, 2019

[12] Amulya bhattacharya, Indian Medical Gazetteer, Thackers press & directories Ltd, Calcutta, 1932, p.392.

[13] Amulya Bhattacharyya, Op.cit.,p.391.

[14] Dethloff, W. (1944). *Chinin*. Verlag Chemie. p.28.

[15] Administrative Report of the Government Cinchona Department for the year (1959-1960), Government of Madras, 1960.

[16] G.O No.1606, Dated 9th July 1937, (International Conference of Malariology), Health Department

[17] G.O No.292, Dated 6th July 1867, (Government Quinologist),Public Department.

[18] Madras Presidency Administrative Report 1884-1885, p.76

[19] G.O No.1457, Dated 21st October 1935, (Private Planters),Development Department.

[20] Lucy veale , A Historical geography of the Nilgiri cinchona plantations -1860-1900, University of Nottingham, 2010, p.263

[21] G.O No 578, Dated 16th April 1943, Development Department

[22] G.O No 961, Dated 4th June 1943,Development Department

[23] Lucy veale,op.cit.,263

[24] Interviewed: Mr.M.Ingar sal, Draughting officer, (1/12/2020)

[25] G.O No.786, Dated 8th April 1932, (Quinine free Distribution Scheme), Development Department.

[26] G.O No.1228, Dated 18th March 1953 (Quinine), Development Department.

OCCUPATIONAL SHIFTS AMONG GYPSIES OF COIMBATORE IN A MODERNIZING ECONOMY

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Abstract

The Gypsies are Indigenous people, one of the nomadic communities in Southern India. Tamilnadu is home to several nomadic communities, and one such community is Kuravar or Narikkuravar/Nari Koravan or Kuruvikkaran. According to the census in 2011, their population is estimated to be about 30,000 in Tamil Nadu. The main occupation of Gypsies is fox hunting and selling their teeth, skin, etc., As the government has banned hunting of wild animals and possession of firearms, they have changed their occupation to bead-making. This research paper looks into how economic development like industrialization, urbanization, and changes in socioeconomic policies have impacted the Gypsy community in Coimbatore. Through qualitative research methods, the study examines how this marginalized community has adjusted to these shifting economic conditions. The results enhance our understanding of the opportunities and challenges faced by the Gypsy community in a modernizing economy. Furthermore, the paper suggests policy measures to support fair and inclusive development.

Keywords: Economy, Gypsy community, Occupation, Sustainable livelihood.

1. Introduction

In a diverse landscape with numerous castes, there are around 70 different types of Kuravars. This paper focuses specifically on the Gypsy community. Traditionally, Gypsies are a nomadic group known for hunting foxes and earning a livelihood by selling their skins, teeth, and nails. However, with the government's ban on hunting wild animals and possession of firearms, they have shifted to bead-making as their primary occupation. During British rule, the Gypsies were stigmatized under the Criminal Tribes Act of 1871, which labeled them as criminals and granted local authorities increased power over them. This historical injustice has had a lasting impact, despite the Act's repeal in 1952. The stigma associated with the community persists in societal attitudes. Today, Gypsies are dispersed across several states in India, including Tamil Nadu, Kerala, Andhra Pradesh, Kolkata, Rajasthan, Karnataka, Gujarat, Madhya Pradesh, Delhi, Uttar Pradesh, and Odisha. According to the 2011 census [1], their population in Tamil Nadu alone is estimated at around 30,000. They are a branch of the Vaagri family and are known by various names in different regions. Their language, Vaagriboli, is an Indo-Aryan language that lacks a written script.[2]

This research paper looks into how economic development like industrialization, urbanization, and changes in socioeconomic policies have impacted the Gypsy community in Coimbatore. Through qualitative research methods, the study examines how this marginalized community has adjusted to these shifting economic conditions. The paper suggests policy measures to support fair and inclusive development.

2. Methodology

2.1 Area of Research

The Narikkuravar (Gypsy) community in Coimbatore is a marginalized group that faces discrimination and social isolation. They are migratory by nature. Throughout history, they have been urged to change their way of living and move to permanent settlements. While some Gypsies have embraced this shift and now live in fixed communities, many continue to uphold their nomadic traditions. In Coimbatore, they can be found in areas such as Karamadai, Thudiyalur, Thimmampalayam pudur, Periyanaickenpalayam, Kinathukadavu, Jothipuram, and Press Colony. The researcher exclusively selected the Narikoravar colony at Karamadai in her study to gain a deeper understanding of their unique challenges and adaptations.

2.2 Objectives of the study

- To examine the traditional occupations and economic dynamics.
- To identify the factors leading to occupational shifts.
- To analyze the challenges faced by the Gypsy community during occupational shifts.

2.3 Research Design

Descriptive research design

2.4 Sample

The Narikoravar colony in Coimbatore consists of 220 Gypsy families. The snowball sampling method is used to get the samples. During the process of data collection, a semi-structured interview schedule is used to get the samples from four women and four men from the Narikoravar colony, Karamadai. The interviews were recorded and transcribed verbatim for analysis.

2.5 Data collection

Participant observation, in-depth interviews, and document analysis were conducted. An extensive field survey was conducted, utilizing questionnaires, interviews, interactions, discussions, and case studies to provide a comprehensive perspective for the study. Information from local newspapers and journals was included, and published articles and books related to the topic were verified.

2.6 Data analysis

The data were collected in April 2024. The data is analyzed through interpretive analysis from the interviews of the gypsies.

3. Narikkuravar – origin

The history of Narikkuravar (Gypsy) can be traced back to North India before migrating to South India. Around the 6th century CE, they may have moved from Gujarat and southern Maharashtra to Tamil Nadu. Linguistic evidence indicates their Indo-Aryan origins. Edgar Thurston suggests that the Gypsies are related to the Khonds of Orissa.[3]

There are various theories about the origin of the Gypsies:

1. One theory suggests that about 600 years ago, Mughal rulers in North India compelled these people to embrace Islam. Resisting this compulsion, they migrated to Southern India.[4]
2. Another theory proposes that they might have followed the Mughals during their invasion of India. [5]
3. According to the third theory, they were soldiers in Chhatrapati Shivaji's army. As the Marathas began to lose battles to the English and faced decline, the Gypsies may have migrated to Southern India. According to Vishnu Dasan's theory, the Gypsies were forced to seek refuge in hill tracts, where they adopted a nomadic lifestyle centered

around hunting. They continued this nomadic way of life even after migrating to Tamil Nadu. There was a mythological view that these nomadic tribes became hunters (shikaric) due to the curse of Sita.[6]

4. Traditional Occupations and Economic Dynamics

Narikkuravar (Gypsy) pursued different occupations as the means of their livelihood. Historically, they were engaged in hunting, catapults making, etc., nowadays they are found engaged in selling beads and fancy items, tattooing, fortune telling, honey collecting, etc.,

4.1 Hunting

In the early period, their main occupation was hunting. Gypsy people normally hunt during the Tamil months of Puratasi (September-October) through Thai (January-February), as this period is particularly advantageous for hunting. They avoid hunting in Margazhi (December-January) because it is the hatching season, and they do not wish to harm mother birds that are feeding their young ones. During some months, they hunt at night. Using guns, they target small animals such as birds, foxes, wild boars, hares, wild cats, wild civets, and toddy cats. They also set traps to capture grey partridges, grey quails, jungle fowl, and wild doves. Nets are used to catch birds, foxes, wild boars, hares, wild cats, wild civets, and toddy cats. Furthermore, they use explosives to hunt foxes. Since foxes damage standing crops, villagers often enlist the help of the Gypsies to control their population. They use goat fat mixed with pepper for fox hunting. The fat is melted and combined with pepper, which foxes find highly attractive. This mixture is also combined with gunpowder, causing an explosion when the fox bites the pepper-coated bait. They possess government-licensed firearms and use them to hunt cranes, ducks, cuckoos, fowl, and crows.[7]

4.2 Ammi kothuthal (Grinding Machine)

The grinding stone is traditionally used for various purposes, such as grinding rice to make idli. To maintain its grating efficiency, the surface of the grinding stone must be periodically roughened. Gypsy women are particularly skilled at this task. In the early period, these women were paid in kind. They were paid in millet (kambu), ragi (kelvaragu), rice (nel), Sorghum (solan), tamarind (puli), dhal (paruppu), and paddy.[8]

4.3 Catapults making

During the early period, the Gypsy people crafted catapults for hunting. They built a Y-shaped wooden catapult, attached to a sling. These catapults were Y-shaped wooden devices with an attached sling. Nowadays, Y-shaped wooden molds have been replaced by Y-shaped plastic molds. The Gypsy people produce these catapults for sale at village fairs and public places. Farmers also use these catapults for bird hunting.[9]

5. Modern Occupations of Gypsies

5.1 Collecting honey

As a community of hunters, the Gypsies have extensive knowledge of the forest and can locate beehives with precision. To collect honey, they climb steep rocks or tall trees using ropes. They gather the honey using sickles, plastic buckets, and other tools. To protect themselves from bee stings, they often cover their bodies with bags. After collection, the honey is cleaned and bottled. In the past, they sold bottles of honey on the streets, but now they sell it to local medicine dealers.[10]

5.2 Bead making

The principal occupation of the Gypsy community today is bead-making, earning them the popular title of "bead people." This traditional skill has become a major source of entrepreneurial activity. The Gypsies are skilled at crafting colorful necklaces from a variety of materials and sizes, producing designs that range from simple to intricate. These beads made from glass, clay, crystal, jewels, rudraksha, navaratna, and other raw materials, are strung on copper and silver wires. The artistic sensibility and technical skill required for bead-making are cultivated through socialization and passed down through generations, starting from childhood. Their culture is deeply rooted in this craft. Bead-making and selling are primarily carried out by women, who can frequently be seen crafting bead garlands and selling them in front of temples, markets, and rural areas. These items are often priced higher than similar products due to their intricate craftsmanship.[11] The Gypsies travel to distant northern regions to purchase beads, rudraksha, crystals, and other materials at lower costs, buying them in bulk, processing them, and then selling the finished products. They carry essential tools, such as cutting pliers, in shoulder bags and often continue bead-making while traveling. Some of these women have partnered with non-governmental organizations to receive training in jewelry-making, aimed at improving their skills and enhancing their profiles. However, due to a decline in the market for bead items, some Gypsy have transitioned to other occupations.[12]

5.3 Tattooing

The 'pachai kuthal' or 'pachakuthurathu,' meaning 'pricking with green,' is an art form the Gypsy tribe in Tamil Nadu has had historical associations with. In Coimbatore, they were known as pachakutra kuravars. A permanent tattoo is made on the skin using a needle, this traditional local art has been taken up as a profession by a small number of gypsies. Tattooing is a practice that existed even in the Mughal period where hot iron rods were used to identify slaves by marking them on the forehead. Tattooing was identified with social identity, clan, group, and kinship. The Gypsies used thorns and later changed to needles for tattooing. The designs are drawn onto the skin manually, and then the process provides for a blunt stick to be dipped in a mixture of lampblack, lamp oil, and turmeric carried in a half coconut shell. It is by pricking the patterns onto the skin with four or five needles that are tied together that a tattoo mark is made. Antiseptic herbs, breast milk, and sterilized thorns were the ways to ensure the process of tattooing was safe. Knowing the risk of infection from an untreated needle, they sterilized it so there would not be a complication. It is very considerable knowledge of infection control for a nomadic community. After applying new tattoos, the aftercare was to use turmeric and oil to soothe.[13]

Today, the Gypsies have moved into the twenty-first century with tattoo machines and tattoo guns. Flowers, traditional kollams, animals, names, and crops are popular tattoos. Most tattoos are done on the arms and the chest. When some clients ask for letters, the Gypsies who themselves cannot read and write are known to get the client to write what he or she wants in the part of the body that is to be tattooed, and then ink it exactly as written. This evolution in tattooing skills has contributed to the modern tattoo culture. What was earlier practiced on the roadsides has now found a place as a modern tattoo art studio setting.

5.4 Trade

The members of the Gypsy community are involved in various commercial activities. They move from street to street, selling the commodities that they have prepared themselves, such as bead garlands and needles, using iron they have smelted themselves. [14] They are vendors who go from place to place, targeting places with large crowds. They maximize their sales during festivals, which significantly boosts their profits. Although many of their products are relatively low-end, the craftsmanship and business acumen of the Gypsies are exemplary. Their products are widely accepted and have captured a broad market. Their sales extend beyond state borders, where they find profitability. They produce export-quality bead articles and value-added handicrafts. This traditional craft is threatened by mechanization, urbanization, and commercialization. Government-sponsored exhibitions offer special stalls for displaying their products. Banks have now come forward to offer loans to improve business prospects. Additionally, some Gypsies resort to borrowing money from private lenders to support and expand their businesses.

5.5 Retail

The Gypsy community continues to sell their products and also purchases items from wholesalers, which they sell in their unique way. Their stock includes a variety of fancy items such as glass bangles, necklaces, mirrors, hairpins, kumkum, cosmetics, combs, money purses, balloons, waist strings, black and red thread, framed pictures of deities, rubber bands, funnels, cleaning brushes, dolls, camphor, nail polish, lipstick, saffron powder, false hair (sovuri), collyrium (or mascara), hooks, naphthalene balls, and color powder used for kolam. In areas with large crowds, they display their retail products on the floor.

5.6 Medicine

Today's world of medicine has witnessed tremendous changes, with various treatment methods such as Allopathic, Ayurveda, Yunani, Siddha, and Herbal Medicine available. Despite these advancements, tribal communities continue to practice traditional medicine. For example, the Gypsies community relies on herbal medicine. Initially, they carried traditional remedies in small bags and promoted their products by visiting households in each village and town. They often stayed in one place for a year or two to distribute their remedies and, in some cases, established regular medical shops in urban areas. In herbal medicine, they use roots, leaves, fruits, stems, tubers, and other plant parts for therapeutic purposes.[15] Although the Gypsies may not possess modern medical knowledge, they are equipped with extensive traditional knowledge and skills. This expertise enables them to diagnose diseases and prescribe appropriate medicinal plants to treat symptoms.

6. Factors leading to occupational shifts

Occupational shifts across the wider economy can have an impact on the traditional occupations of Gypsies.

1. As Gypsy communities moved to urban cities, they might have changed from their usual jobs like hunting or making catapults. Instead, they could have started urban jobs that helped them make a living such as bead-making, selling fancy items, or running small businesses.
2. Discrimination and social exclusion can make it hard for Gypsy people to get their traditional jobs. This might

push them into unofficial work or starting their businesses. Even in these areas, they might face unfair treatment, but the need to earn money often comes first.

3. Getting an education can lead younger gypsies to choose new career paths. Education opens doors to jobs that can offer more security and better pay than the work gypsies traditionally do.
4. Shifts between generations and in Gypsy culture can also shape career choices. Younger gypsies might not want to do the same work as their parents. This could be because they're fitting in with wider society, their values are changing, or they want different things after seeing how others live.
5. Government policies and programs shape Gypsy livelihoods in major ways. Laws that limit traditional nomadic practices may push gypsies to settle and find new income sources.
6. The spread of global connections opens up fresh business chances and hurdles for Gypsy groups. They might start selling fancy items or making beads for customers beyond their usual community.
7. Some Gypsy individuals aim to climb the social ladder through education and occupation, moving away from work linked to lower social and economic standing.

7. Challenges faced by the Gypsy community during occupational shifts

The Gypsy community faces significant challenges as they navigate changes in their occupations, which impact both their economic stability and cultural identity. Persistent stereotypes and discrimination continue to hinder their access to education, jobs, and social services, and these issues are magnified when they seek new or more stable employment. Traditionally, the Gypsy has depended on roles such as hunting, tattooing, and crafting catapults. However, recent environmental policies limiting forest access and the pressures of modern life have disrupted these traditional practices, leading to financial struggles. As the community shifts away from these traditional jobs, individuals often experience a sense of marginalization. Those who try new types of work might feel disconnected from their cultural roots, while those who hold onto old roles may find themselves isolated from broader society. The lack of formal education and job training historically available to the Gypsy has made it difficult for them to adapt to today's economy. Without the necessary skills and qualifications, finding work in new fields becomes challenging, and the transition from self-employment to formal employment can exacerbate financial instability. Traditional occupations are not just a source of income; they are also vital to the Gypsy's cultural identity. As these roles fade, there is a risk of losing cherished cultural practices, language, and community bonds. Compounding these issues are insecure land rights and inadequate housing, which add to the uncertainty they face. Environmental restrictions further impact their traditional livelihoods, making economic hardship even more acute. These shifts in employment can take a toll on Gypsy's physical and mental health, leading to increased stress, poorer living conditions, and limited access to healthcare. The divide between older and younger generations may widen, with older members valuing traditional ways and younger ones pursuing modern opportunities, potentially leading to a loss of cultural continuity.

8. Opportunities for the Gypsy Community in the Modern Economy: Government Initiatives

The Tamil Nadu government is making significant strides to support the Gypsy community, aiming to create meaningful change in their lives. A key initiative is the Chief Minister's Solar-Powered Greenhouse Scheme (CMSPGHS) [16], which helps Gypsy families build sturdy homes equipped with solar panels. This initiative not only improves living conditions but also promotes sustainable living practices. In the realm of education, the Adi Dravidar and Tribal Welfare Department are actively working to support Gypsy students.[17] By providing scholarships, textbooks, and uniforms, the department is helping to overcome barriers to education. Research by the National Institute of Educational Planning and Administration (NIEPA) shows that such targeted support can significantly boost school enrollment and academic performance for marginalized communities.

Skill development is another area of focus. The Tamil Nadu government has established centers offering job training in fields like handicrafts, tailoring, and small business management. These programs, supported by the Ministry of Skill Development and Entrepreneurship, are designed to improve job prospects and increase income potential for the Gypsy community. To enhance market access for Gypsy artisans, both government agencies and NGOs are working together. E-commerce platforms such as Nakuras[18] are crucial in helping artisans reach a broader audience, both within India and internationally. Social welfare programs also play a vital role in supporting Gypsy families. Initiatives like the Chief Minister's Comprehensive Health Insurance Scheme,[19] Old Age Pension, and Pension for Widows provide essential support. The government's plan to distribute small plots of land for housing and farming aims to secure land rights and improve living conditions. This aligns with the Tamil Nadu Town and Country Planning Act 1971 (Act 35 of 1972), which highlights the importance of secure land rights for social and economic stability. Additionally, providing essential identification documents such as AADHAAR cards, ration cards, and voter IDs helps Gypsy individuals access government services and participate in social programs. Research from the Unique Identification Authority of India (UIDAI) highlights that having proper identification is important for accessing services and benefits, which fosters greater social inclusion.

8.1 Government initiatives on reducing Ethnic Restrictions and Enhancing Rights

The Gypsy community has faced significant ethnic restrictions historically, including social exclusion, economic deprivation, and a lack of land ownership. Addressing these challenges requires solid government intervention. Since March 17, 2023,[20] the government has implemented a reservation system in education and government jobs to support Scheduled Tribes (ST), including the Gypsy. Tribal Sub-Plan (TSP) Programs aim to assist tribal communities with essential services such as housing, health, and education.

Educational and housing schemes, such as the Sarva Shiksha Abhiyan (SSA) [21] and the Mid-Day Meal Program, aim to improve enrollment and retention rates among tribal students. These initiatives focus on providing better access to education.

Pradhan Mantri Awas Yojana (PMAY) scheme [21] provides affordable housing to both urban and rural poor, including tribal households. MGNREGA (Mahatma Gandhi National Rural Employment Guarantee Act) ensures guaranteed wage employment for rural households, including tribal communities, to generate income.
Ministry of Tribal Affairs implements various schemes such as the Vanbandhu Kalyan Yojana and National Tribal Research Institute to coordinate tribal development and policy planning. Scheduled Tribes and Other Traditional Forest Dwellers (Recognition of Forest Rights) Act 2006 recognizes the rights of forest-dwelling tribal communities, including the Gypsy, over forest resources. Tamil Nadu Gypsy Welfare Board was established in 2015 under the Tamil Nadu Adi Dravidar Housing and Development Corporation Act, this board provides a legal framework for implementing development programs for marginalized communities like the Gypsy.

9. Findings

Based on the research, the findings are,

1. The research highlights a notable shift in occupational patterns among the Gypsy community in Coimbatore, influenced by modernizing economic factors. Traditional occupations like hunting and bead-making are gradually giving way to opportunities in Trade and Retail. This shift reflects broader changes in the local economy and shows how the Gypsy community is adapting to new economic realities.
2. The transition from traditional to modern occupations presents both challenges and opportunities for the Gypsy community. The findings highlight the need for targeted policies that support skill development, access to formal employment, and social protections to mitigate these challenges.
3. Despite the existence of various welfare schemes for the Gypsy community, many are unaware of these opportunities. Government initiatives aimed at supporting the Gypsy often fail to be effectively implemented at the grassroots level.
4. The research explores the tensions between cultural preservation and economic integration among the Gypsy community in Coimbatore. As community members increasingly participate in mainstream economic activities, there is a concern about potential cultural erosion and the loss of traditional practices. The findings highlight strategies that the community employs to preserve cultural identity while engaging in the modern economy, such as integrating traditional craftsmanship into marketable products.
5. The research identifies cases where supportive government policies, such as skill development initiatives, have facilitated smoother transitions into new occupations. However, challenges persist in ensuring these policies are inclusive and effectively reach marginalized communities like the Gypsies.

10. Recommendations

Based on the research, several key issues have been identified that require government intervention- the recommendations are,

1. The government should focus on raising awareness about Gypsy rights and available schemes.
2. To better support the Gypsy community, the government should conduct regular assessments of their

social and economic status. Such research can provide valuable insights for developing targeted policies and programs.

3. Many government initiatives are not effectively implemented at a grassroots level. These programs must be properly executed to address this and reach the intended beneficiaries.
4. Enacting anti-discrimination laws like the Scheduled Tribes (Prevention of Atrocities) Act,1989 can significantly help by prohibiting ethnicity-based discrimination, thus providing essential support to the Gypsy community in Coimbatore.
5. Incorporating the history and culture of the Narikkuravars (Gypsy) into school curricula can broaden students' understanding of diverse cultures and reduce prejudice. This approach promotes a more inclusive and empathetic learning environment.
6. The government should also invest in skills training programs to create more job opportunities and empower individuals with the tools they need for success. Funding these programs and ensuring transparency in how resources are allocated is vital for addressing and reducing ethnic and tribal barriers.

By taking these steps, the government can significantly contribute to the empowerment and upliftment of the Gypsy community, improving their quality of life.

10.1 Limitations of the Study

Though efforts are made to collect accurate and reliable data, accuracy and reliability depend on the availability of reliable sources. Since the study was conducted with only a small number of samples, its results cannot be generalized to the entire Narikkuravar (Gypsy) community.

11. Conclusion

The Narikkuravar (Gypsy) community in Tamil Nadu has experienced significant changes due to modernization and legal reforms, shifting from traditional fox hunting to bead-making. This transition highlights both the strength of the community and the challenges they face in adapting to a modernizing economy. To effectively support this marginalized group, targeted government intervention is essential. Policies should focus on enhancing the implementation of existing initiatives, investing in skills training, and promoting cultural awareness to combat prejudice. Enacting anti-discrimination laws and ensuring transparent funding are crucial for ensuring fair treatment and equitable development. Future research should monitor the long-term effects of these changes and evaluate the success of the policies that have been put into place. By addressing these needs, we can assist the Gypsy community in navigating economic shifts while preserving their cultural heritage and improving their socioeconomic opportunities.

12. Reference

[1] Census of India 2011 Report, 2011, Government of India. Retrieved from http://censusindia.gov.in/
[2] G. Srinivasa Varma, 1970, Vagriboli; An Indo-Aryan Language, Annamalai University, p. i.
[3]Edgar Thurston and K Rangachari, Castes and Tribes of Southern India-volume 3, 1909, Government Press, Madras, p.438-504.
[4] Padma Bharathi, Karasur, 2004, Narikuravar Ina Varaiviyal, Thamizhini, Chennai, First edition, p. 182.

[5]G. Srinivasa Varma, 1978, Narikkurava palangudi Makkal, anaithinthiya Tamil mozhiyier kazhagam, Annamalai Nagar, Chidambaram, p. 8-9.
[6]Bhakthavatsala Bharathi, 2011, The Vaagri in Tamilnadu: Ethnographic Perspectives, Social History of Tamil Vaagri, National Folklore Support Centre, p.4.
[7] Interview with Micheal Raj (35), Narikoravar colony, Karamadai, on 4th April 2024.
[8] Interview with Vennila (38), Narikoravar colony, Karamadai, on 4th April 2024.
[9] Interview with Manikandan (41), Narikoravar colony, Karamadai, on 4th April 2024.
[10] Interview with Palanisamy (48), Narikoravar colony, Karamadai, on 4th April 2024.
[11] Interview with Vairam (42), Narikoravar colony, Karamadai, on 4th April 2024.
[12] Interview with Selvi (34), Narikoravar colony, Karamadai, on 4th April 2024.
[13] Interview with Thangavelu (51), Narikoravar colony, Karamadai, on 4th April 2024.
[14] Interview with Vadivu (65), Narikoravar colony, Karamadai, on 4th April 2024.
[15] S Vijay, 2014, A Socio-economic perspective on the occupations of Narikkuravars in Tamilnadu, Proceedings of the Indian History Congress, Vol. 75, Platinum Jubilee, p. 1232-1240.
[16] G.O.(Ms.) No.47, Rural Development and Panchayat Raj Department, dated 15th June 2012. Date of retrieval: 24th March 2024.
[17] G.O.(Ms.) No.24, Adi Dravidar and Tribal Welfare Department, dated 21st February 2020. Date of retrieval: 16th June 2024.
[18] https://nakuras.myinstamojo.com/
[19] G.O.(Ms.) No.345, Health and Family Welfare Department, dated 30th September 2022. Date of retrieval: 8th April 2024.
[20] G.O.(Ms.) No.100, School Education Department, dated 16th May 2018. Date of retrieval: 15th June 2024.
[21] G.O.(Ms.) No.36, Rural Development and Panchayat Raj Department, dated 17th March 2023. Date of retrieval: 16th June 2024.

HISTORY OF DEMOGRAPHIC STUDY IN INDIA WITH SPECIAL REFERENCE TO MADRAS PRESIDENCY FROM 1881-1941- A STUDY

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Abstract
The present study explores the evolution of demographic patterns in India during the colonial period (1881-1941), with a specific focus on Madras Presidency. This era saw the start of systematic censuses, with the first comprehensive census of India being conducted in 1881. The demographic history of the Madras Presidency, a large administrative division under British rule, is critical for understanding larger trends in South Indian society. A varied and heavily populated area, the Madras Presidency included portions of modern-day Tamil Nadu, Andhra Pradesh, Kerala, and Karnataka. During this time, the British administration instituted the regular decennial census, which became an important tool for policymaking and administration. These censuses collected a wide range of information, including population number, density, dispersion, and a variety of social and economic factors such as age, gender, occupation, religion, and literacy rate. The population trends recorded in this area were impacted by a multitude of causes, such as migration patterns, public health initiatives, famines, and colonial economic policies.

Keywords: Census, Demographic, Literacy Rate, Madras Presidency, Population

1. Introduction

In 1881, the British colonial government in India conducted its first comprehensive census. This marked the beginning of a new era in India's demographic studies. The region's population was diversified, with various levels of economic development, urbanization, and educational and healthcare access. Between 1881 and 1941, the Madras Presidency had rapid economic growth, fueled by expansions in agriculture, manufacturing, and commerce. Demographic research identified tendencies such as high population increase and variances in birth and death rates. These trends had a significant impact on economic development, such as the expansion of industries such as textiles and manufacturing, urbanization creating new markets for trade and commerce, and changes in age structure and birth rates influencing demand for education and healthcare.

2. Research Methodology and Sources for the study

The Present study is based on both the Primary and Secondary Sources. Primary Sources like Census Report, Famine Commission Reports, Madras Administration Reports and Gazetteers are referred.

The Secondary Sources like books, published, un-published works and newspapers were collected from Tamil Nadu Archives, Connemara Library, Madras University are also referred for the study. The

study is both Quantitative and Qualitative in nature.

3. Meaning and Definition

Demography refers to the systematic and scientific study of human population. The name "demography" has a Greek origin and is composed of two words: demos (people) and graphy (describe), which signifies "the description of people" [1]. The scientific study of human population encompasses the analysis of changes in population size, composition, and dispersion. Demography is the study of the population and its composition, as well as the numerous trends and processes connected with it, such as changes in population size, birth, death, and migration patterns across age groups. which comprises census or survey and the systematic collection of data on the individuals dwelling within a certain region. [2].

4. Importance of Demographic data

Demographic statistics gives information on population size, distribution, and composition, which is used in policymaking, implementation, economic development, and public welfare. A community's health state is defined by the dynamic interaction of population number, structure, and dispersion. Demographic characteristics aid in health care planning, laying the groundwork for projecting future events and making informed decisions concerning the creation, implementation, and assessment of programs, policies, education, housing, health, employment, and other forms of social services. [3].

5. Demography and Population Studies

The study of human population is mainly known as Demography and Population studies. The Population studies are concerned with understanding what are the kinds of changes taking place in the size and nature of human population. Demographic determinants such as fertility, mortality and migration are the three basic aspects which influence the population of a particular place. Most demographic concepts are expressed as rates or ratios and they involve two numbers [4].

6. History of Population Studies

During the middle of the seventeenth century, population studies emerged in England, France, Germany, and a few other European countries. John Graunt, who is regarded as the Father of Demography or Population Studies, observed mortality, fertility, and migration. The “Bills of Mortality” from which Graunt obtained the data for his analysis were current reports of burials and christening in a population of nearly half a million persons in London and its environs. These reports were compiled and maintained regularly from 1603 onwards by parish clerks. Graunt assembled the data for the period 1604-1661 and prepared as a report, which is regarded as the first systematic and objective study of population [5].

7. Development of Demography studies in India

According to the earliest literature "Rig-Veda," India's population was nearly steady from 800-600 BC. Kautilya’s "Arthasastra,"advocated the use of demographic data to assess state taxation practices. The administrative report of "Aini-Akbari" compiled by Abul Fazal during the reign of Mughal Emperor Akbar contains detailed information on the population, industry, wealth, and other features [6].

8. The History of Census under British Raj

The first British colonial Census was done in 1800. Later, Censuses were conducted in Banaras from 1827 to 1828 and

Allahabad in 1824, both under the guidance of James Prinsep. Henry Walter conducted the first Indian city census at Dacca in 1830. The second Census was conducted by Fort St. George between 1836 and 1837[7]. The first non-simultaneous census was held in 1872 under Governor General Lord Mayo, while the first simultaneous census was taken in 1881. After that, a Census conducted once in every ten years.

The 1881 Census was the first organized census conducted over the Indian subcontinent. Census Day in 1881 was scheduled on February 17th. Except for the parts ruled by the French and Portuguese, the entire country was covered, including the 11 British provinces and seven princely realms. Act XIV of 1880 established the legislative procedures for the census [8]. On February 26, 1891, a second census was held. Sikkim and the northern region of Myanmar (Burma) were given more attention. Some Census documents were translated into various Indian languages [9].

On March 1, 1901, the third Census of 1901 was conducted. Under the superintendent of British territory in the Indian subcontinent, each enumerator was allotted a Census block of 30-35 houses. Hindu caste, Jains and other religions names for tribes or castes were recorded [10]. On March 10, 1911, the Indian Census was conducted. This Census saw the implementation of many innovative programmes. Wooden planks were fastened to the walls according with the number of houses. The Provincial Superintendent's General Village Register had already been prepared & Census materials were translated into native languages [11].

The Census was held on a single day throughout India on March 18, 1921 and the Census Moussa Registration system was launched. The "Non-Cooperation Movement" led by Mahatma Gandhi impacted the Census procedure across India. According to Indian Census statistics, 1.2 to 1.7 crore deaths were reported from "flu" from 1918 to 1920 as a result of the 1918 influenza pandemic, often known as the Spanish flu, caused by the "H1N1 influenza-A" virus that swept all over the world [12]. On February 26, 1931, India's sixth Census was conducted. The Temporary Census Act of 1929 (Act X of 1929) governed the 1931 Census. Civil Disobedience Movement had an impact on the 1931 Census. It was seen as successful British Census effort in India [13].

The Census was conducted on March 1, 1941, in accordance with the Census Act of 1939 (Act XXIV of 1939). It was the last Census conducted in pre-independence India by the British Government. The 1941 Census was planned to be conducted concurrently across India but due to World War II, the British financial crisis, and widespread anti-British sentiment as part of the Indian freedom struggle, the plan could not be fully completed. The new Census schedule was created to streamline the computation process and made it easier to assemble. To count the population, some machines were introduced. The outputs were relatively limited, and several sub-tables in the Census data were omitted [14].

9. Benefits of conducting census during British Raj

9.1 Administrative Efficiency:

Accurate demographic data aided the British colonial government in resource allocation, revenue collecting, and public service delivery.

9.2 Economic planning:

Census data influenced decisions about infrastructure development, trade, and commerce in madras presidency.

9.3 Societal Reform:

Census data revealed societal challenges like poverty, education, and healthcare, resulting in reforms and initiatives.

9.4 Public Health:

Census data helps to track disease patterns, resulting in more targeted health interventions and better healthcare infrastructure.

9.5 Education:

The census results influenced education policy, resulting in increased investment in schools and educational infrastructure.

9.6 Urban planning:

Census data influenced urban development, including housing, sanitation, and infrastructure design.

9.7 Political representation:

Constituency boundaries and political representation were calculated using census data.

9.8 Research and analysis:

Census data help in studying demographics status, sociology, and economics condition of a particular region.

9.9 Improved governance:

Census data helped the colonial government to track progress, review policies, and made informed.

9.10 Legacy for Independent India:

The census data gathered at that time set the groundwork for post-independence planning and development of nation. These advantages had a long-term influence on the region, moulding its development and setting the framework for future

10.The Comparisons of Census Methods

Census in pre-Independent	Census in Post Independent
Manual data collected using paper forms.	Electronic data collection using digital formats.
Data were processed manually, leading to errors and delays.	Electronic scanning and machine learning algorithms improved data accuracy and efficiency.
Minimal use of technology	Utilized GPS and mapping technology
Emphasis on basic demographics (age, gender, occupation)	Increased emphasis on socioeconomic statistics (income, education, health, etc.).
Informing tax policy, infrastructure development, and resource allocation.	Making informed decisions on economic development efforts, urban planning, and labour market analysis.
Identifying socioeconomic concerns such as poverty, education, and healthcare.	Targeted interventions for healthcare, education, and social welfare programs, as well as research and analysis in sociology, economics, and public health.

11. The History of Madras Presidency

Queen Elizabeth-I authorized the formation of the East India Company, a strong private trade organization [15]. The East India Company was founded by merchants seeking to benefit from trading in Asia for spices, cotton, and indigo dye in England. In 1639, a company representative acquired property in southern India. The East India Company erected Fort St George at this area, which is now part a of Chennai. The Mughal emperor first welcomed the English tradesmen. around the 1600s gradually English traders increased their commerce in India, established several trading centers and factories in the country. Siraj Ud-Daulah assumed the title of Nawab of Bengal in 1756. In 1757, Ud-Daulah conquered Fort William, a British fort in Kolkata, after the British refused to stop expanding it. The British, headed by Robert Clive, planned to retake the fort, and the two sides met at Plassey. After Britain's victory at the Battle of Plassey, the East India Company's private army deposed certain Indian princes [16]. Madras Presidency was established in 1801. It was a significant province of British India, popularly known as Madras Province and formally as the Presidency of Fort St George. It included the modern southern India, including the states of

Tamil Nadu, Kerala, Andhra Pradesh, Karnataka, portions of Odisha, and the Union Territory of Lakshadweep.

The Presidency's capital was Madras, which is today known as Chennai. In 1862, the province was split into 22 districts. Then it was divided into 24 districts [17]. In 1911, the province was further split into 26 districts, including North Arcot, South Arcot, Chingleput, Madras, Salem, Coimbatore, Trichinopoly, Tanjore, Madura, Ramnad, Tinnevelly, and Nilgiris in Tamil Nadu. It remained under British administration until 1947. The first British Governor of the Madras Presidency was Edward Clive, and the final Governor was Archibald Edward Nye. After 147 years of existence, the Madras Presidency was renamed Madras State in 1947, when India attained freedom. In 1956, the Madras State was divided into four regions, each with thirteen districts. It was formally renamed to Tamil Nadu in 1967 [18].

12. Demographical Condition of Madras Presidency 1881-1941

The growth rate of Madras Presidency population has not always been very high. The population in British territory at the last four enumerations has been 31,220,973 (1871), 30,827,218 (1881), 35,630,440 (1891), 38,209,436 (1901) [19]. The decline of 15 per cent in 1881 was due to the famine of 1876-78. According to the 1901 census the largest and most populous District Vizagapatam had an area of I7,200 square miles and 2,900,000 inhabitants. According to the census of 1921 total population was 42,318,985 in Madras Presidency. The Madras Presidency covered an area of 142.277 square miles with a population of 46,740,107 according to the 1931 Census, Madras ranked third in population and fifth in density among the major provinces. Its rate of increase over the decade was 11.91 in British territory [20]. The birth rate and death rate of Madras Presidency between 1881-1941 was very high due to famine, world wars, epidemics etc. Tanjore District had high population density (1881-1941) and led to labour shortages, driving up wages, and resulted in overcrowding and poor living conditions.

Coimbatore District: Textile industry growth (1881-1941) led to increased employment opportunities, but also perpetuated low wages and poor working conditions.

Decade	Population in million	Percentage increase or decrease in population
1881-1891	-	-1.4
1891-1901	192.5	+14.3
1901-1911	209.0	+8.57
1911-1921	216.3	- 3.47
1921-1931	234.7	+8.52
1931-1941	262.7	+11.91

Table-1
Population growth in Madras Presidency from 1881-1941
Sources: census reports in India 1881,1891,1901,1911

Decade	Birth rate	Death rate	Growth rate
1881-1891	49.2	42.6	6.6
1891-1901	48.1	47.2	0.9
1901-1911	46.3	36.3	10.0
1911-1921	45.2	31.2	14.0
1921-1931	39.9	27.4	12.5
1931-1941	41.7	22.8	18.9

Table-2
Birth and death rate in Madras Presidency from 1881-1941
Sources: census reports in India 1881,1891,1901,1911

13. Literacy rate under British rule [20]

The Madras Presidency had the highest literacy rate of all the provinces in British India. In 1881, Madras had a male literacy rate of 19 percent and a female literacy rate of 8 percent. In 1941, when the Madras Presidency became Madras State, the literacy rate was slightly higher than the national average of 18 percent. Low literacy rates of women (1881-1941) limited labour market opportunities, perpetuated poverty and low wages.

14. Religious Status Under the British Rule [21]

Hinduism was the predominant religion in the Presidency and practised by around 88% of the population.

Year	H	M	B	S	C	Z	J
1881	74.3	19.7	1.3	0.7	0.7	0.03	0.05
1891	72.3	19.9	2.4	0.6	0.8	0.03	0.1
1901	70.3	21.2	3.2	0.7	0.9	0.03	0.1
1911	69.4	21.2	3.4	0.9	1.2	0.03	0.1
1921	68.5	21.7	3.6	1.0	1.5	0.03	0.1
1931	68.3	22.1	3.6	1.2	1.8	0.03	0.1

Table -3
Percentage of Religious Status under British Raj

H* -Hindu C*-Christian
B* -Buddhism M* -Muslim
J* -Jainism S*-Sikhism

15. Language [22]

Tamil, Telugu, Malayalam, Kan nada, Odia, Tulu and English languages all were spoken in the Madras Presidency. Tamil was spoken in the southern districts of the Presidency. Telugu was spoken in north Madras, in East Bellary and Anantapur districts. In the district of South Kanara, the western part of Bellary, Anantapur districts, parts of Malabar were spoken Kannada language. Malayalam was spoken in the districts of Malabar, South Kanara, princely states of Travancore and Cochin, while Tulu was spoken in South Kanara. Oriya was spoken in the districts of Ganjam and Vizagapatam. English was spoken by Anglo Indians and Eurasians. Which was the official language of British India.

According to the 1881 census, there were 14,715,000 people who spoke Tamil, 11,610,000 people who spoke Telugu, 2,324,000 people who spoke Malayalam, 1,699,000 spoke Canarese or Kannada, 640,000 people spoke Oriya and 29,400 people spoke Tulu.The 1901 Census returned 15,182,957 speakers of Tamil, 14,276,509 Telugu-speakers, 2,861,297 speakers of Malayalam, 1,518,579 were speakers of Kannada, 1,809,314 spoke Oriya, 880,145 spoke Hindusthani/Urdu and 1,680,635 spoke other languages. At the time of Indian independence, Tamil and Telugu speakers made up over 78% of the total population of the presidency, with Kannada, Malayalam and Tulu speakers making up the rest.

16. Economic Conditions of Madras Presidency

In Madras Presidency 71% of its people were involved in agriculture, the Madras Presidency produced cereals like as rice, corn, kambu, ragi, sweet potatoes, lady's fingers, beans, onions, garlic, and spices.Food crops accounted for 80% of the total farmed land, with cash crops accounting for 15%. In 1898, Madras produced 7.47 million tons of food grains from 21,570,000 acres of crops on 19,300,000 acres of Ryotwari and inam land. The Land Improvement and Agricultural Credit Act of 1884 sponsored well building and restoration operations. The Madras government undertook large irrigation projects like as the Mettur Dam, Periyar Project, Sudappa-Kurnool Canal, and Rushikulya Project. The Mettur Dam provided water to the western regions of the Madras Presidency, resulting in a 6.94% return on capital expenditure in 1946-47.

17. Wages for Workers in Madras Presidency

The majority of labourers in Madras Presidency were paid just grain. In Coimbatore daily wage labourers were periodically paid a monthly grains, oil, and spices, which was sufficient to support the labourer and his family. In other regions, two or three rupees were provided each year in addition to two clothing and, on occasion, a pair of sandals. Day labourers in Kanara received two grains rice and some curry. Wages were naturally greater nearer to cities and slightly lower in villages.

18. Impact of Economic Policies on Demographical Status

18.1 Industrial Impact

Madras handloom had a significant market in Europe. Cotton, linen, silk, and woolen items and textiles were exported into Europe. Large quantities of goods created by mechanical looms in England were marketed at extremely low costs, posing a threat to the handicraft industries of the Madras Presidency. Madras handicrafts were heavily taxed when shipped outside of the country. This change was a significant impact on India's handloom sector. This resulted in unemployment for a huge number of weavers. Many of them moved to rural areas to work on their farms as agricultural labourers. This resulted in a massive shift in population density.

18.2 Land Revenue

The British arrived India for trade, and then they captured huge areas of Indian land, which required a lot of money to run the business, company projects, and administration, for which the British collected direct and indirect land revenue from peasants. Ryotwari settlement was introduced in numerous sections of Bombay and Madras provinces in the early nineteenth century. Here, land revenue was levied directly on the landowners. As long as the cultivator could pay the revenue, he was considered the land's owner. Farmers were forced to abandon their farms, and agriculture suffered, resulting in food shortages and a shift in population growth [23].

18.3 Commercialization of Agricultural

Commercialization of Agricultural had a significant economic impact throughout the Madras Presidency. Tea, coffee, indigo, opium, cotton, jute, sugarcane, and oilseeds were introduced for different purposes. All farmers were required to grow $3/20^{th}$ of their land for commercial crops. Food grain production dropped as farmers turned to commercial crops. As a result of the limited food supply led to famine in Madras Presidency.

19. Conclusion

The demographic history of the Madras Presidency from 1881 to 1941 reflects a period of significant transformation under colonial rule. The introduction of systematic census operations provided a foundation for understanding population dynamics, while factors such as famines, migration, health crises, and economic changes influenced demographic patterns. The period underscores the complexity of demographic trends and the interplay of various social, economic, and political factors. By studying this era, we gain valuable insights into the historical forces that have shaped the region's demographic landscape, informing contemporary demographic policies and development strategies.

Reference

[1] Shrivastava O.S, “Demography and Population Studies”, Vikas Publishing House Pvt Ltd, New Delhi,1994, p.6.

[2] Tripathi R.S, Tiwari R.P, "Population Growth and Development in India", APH Publishing Corporation, New Delhi,1996, pp.1-6

[3] Agarwala S.N, "Population", National Book Trust India, Madras,1969, p.9.

[4] Chandrasekar. S, "Population & Law in India", Blackie & Sons Publication, Bombay, 1976, p.67.

[5] Mathur. R.N, "Population Analysis and Studies", Chugh Publication, Allahabad, 1986, p.43.

[6] P.K. Nambiar, Census of India 1961, vol IX, Part VIII -A, Madras

[7] Report on the Administration of the Madras Presidency 1881-1882, Government Press, Madras, p.13.

[8] Report on the Administration of the Madras Presidency 1882-1883, Government Press, Madras, p.20.

[9] Census Hand Book (Madras District) 1951, Government Press, Madras, 1953, p.10.

[10] Fort St. George Gazette, Government Press, Madras, 1936, p.21

[11] Charters Molony, Census of India (Madras) 1911, Government Press, Madras, 1912, p.3

[12] Report on the Administration of the Madras Presidency 1921-1922, Government Press, Madras, p.117

[13] Census of India, 1941, Vol- I, Part I, Government of India press, Simla, 1943, p.64.

[14] Chopra P.N, Ravindran T.K, Subrahmanian, History of South India. Vol III, New Delhi, 1979, p.192.

[15] Boag G.T, The Madras Presidency 1881 - 1931, Madras, 1933, p.4.

[16] Ranson, C.W., The growth the of population in Madras Presidency. The Madras centenary commemoration volume, Madras, G.S. Press. 1939, p.8.

[17] G.T. Boag, The Madras Presidency 1881 - 1931, Madras, 1933, p.4.

[18] Census of India, Madras, 1910 - 1902, Vol II, p.2.

[19] Andra Pradesh District Gazette, the State Editor, Andhra Pradesh, 1907, vol-I, p.12.

[20] Census of India, 1921, Vol XIII, Part I, pp.64 -65.

[21] Census of India, 1961- volume IX, Madras part II

[22] Census of India, 1920, vol II, Madras, pp.44 - 45.

[23] Census of India 1911, vol XII, Government Press, Madras, p.9

IMPACT OF SHOLAYAR DAM IN TAMILNADU WITH SPECIAL REFERENCE TO COIMBATORE DISTRICT

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Abstract

The economic status of the Coimbatore municipality of Tamil Nadu, India, is being profoundly altered by the Sholayar Dams, which was built in 1969 to span the Pambar Valley. The main use of the reservoir is for water supply, giving nearby farms a consistent supply of freshwater. This has probably resulted in better yields of crops, better efficiency in farming, and possibly better farmer earnings. Additionally, a dam creates the Sholayar lake by impounding the water that flow into the Pambar Rivers. The dam provides water for consumption, water supply, and generation of hydropower, among other uses.[1] The dam's consistent supply of water has helped other areas that contribute to Coimbatore district's economic inadvertently in addition to its obvious contribution to farmers. Many sectors, like the garment sector, which contributes significantly to the financial standing of the Nilgiri region, depend on a steady supply of groundwater. Furthermore, agriculture, or cultivation of fish, may grow in the area thanks towards the dam's water quality, possibly opening up fresh employment possibilities. Apart from these, the sholayar dam having the socio-economic impact on both the sides as positive and negative.[2] There was the socio impact of the sholayar dam can be splitted into two such as positive and negative socioeconomic factors.

Key Words: Irrigation, Hydroelecrtic Power, Sholayar Dam, Socio-Economic.

Introduction

The Sholayar Dam, constructed in 1969 across the Pambar Valley in Tamil Nadu, has significantly transformed the Economic landscape of the Coimbatore municipality. Primarily serving as a reservoir for water supply, it ensures a reliable source of freshwater for nearby farms, enhancing crop yields and farming efficiency, thereby boosting farmers' incomes. Additionally, the dam supports various sectors by providing water for consumption and hydropower generation. The garment industry in the Nilgiri region and potential fish farming ventures benefit from this steady water supply. However, the dam's impact is multifaceted, with both positive and negative socio-Economic consequences for the region.

Methodology

The study relies on a combination of primary and secondary data. Primary data crucially gathered through personal interviews.

Profile of the Study

This research will explore the environmental and socio-Economic

impacts of the Sholayar Dam, Valparai in Coimbatore District.

Objective of the Study

- To examine the Economic condition of sholayar dam in Coimbatore.
- To identify the benefits and drawbacks of the study.

Research Design

Analytical research design.

Data collection

Primary and secondary data has been collected.

Socio-Economic impact

The Sholayar Dam in Tamil Nadu has had a profound impact on the region since its completion. It generates electricity, providing energy to Tamil Nadu and nearby states, which has helped local industries and reduced reliance on non-renewable sources. The dam also supplies water for irrigation, boosting agricultural productivity and supporting farmers. However, the construction of the dam led to the displacement of local communities, and many have faced long-term challenges due to inadequate compensation and loss of livelihoods. The environmental impact has been significant too, with changes to local ecosystems and water flow patterns affecting biodiversity. Despite these challenges, the dam has been beneficial in many ways. It helps control floods, protecting life and property, and provides a reliable water source for domestic and industrial use, improving living standards. Employment opportunities have been created through the construction and ongoing maintenance of the dam, boosting the local economy. Today, efforts are being made to balance the Economic benefits of the dam with environmental sustainability. Technological upgrades and renewable energy initiatives are being implemented, and there is a focus on involving local communities in decision-making processes. Programs aimed at improving the livelihoods of displaced communities and promoting sustainable agriculture and water management are also being prioritized.

Positive Socio-Economic impact

In general, the Sholayar Reservoir has a major beneficial economic effect on the area since it produces clean electricity, generates jobs, encourages construction of infrastructure, increases tourism, and makes it easier for residents to use the water supply for a variety of uses. It is vital to guarantee all the advantages are fairly dispersed as well as that any possible drawbacks, including community uprooting and harm to the environment, were suitably tackled by means of suitable organizing and handling tactics. The Sholayar Dam has the potential to improve the economic situation and quality of life in the area in a number of aspects.

Negative socio-economic impact

Effective mitigation strategies, thorough planning, as well as involvement of stakeholders are necessary for tackling these detrimental economic effects.[3] The adverse impacts from construction of dams can be lessened and greater equitable and environmentally sound results can be promoted by using techniques including grassroots management of resources, compensatory processes, responsible land use preparation, inclusion relocation policies, and the rehabilitation of ecosystems.

Factors of positive socio-economic

These are the positive factors of socioeconomic impact of sholayar dam

- Irrigation
- Hydro power generation
- Flood control ➢ Infrastructure
- Empowerment opportunity
- Tourism & Recreation
- Education
- Water Management

Water supply for agriculture constitutes one among the Sholayar Dam's main goals. The region's agricultural output has increased dramatically as a result of its plentiful supply of water for farming.[4] Commodities can be grown all year round by farmers, increasing yields as well as profits. This is a significant advantage since it offers a consistent supply containing water for farming, particularly in arid areas. Raising yields of crops and improving agricultural efficiency can boost the incomes of farmers, enhance the availability of local food, and advance the financial wellness of a country as a whole. Farmers have the ability to produce valuable cash crops which may increase their revenue by allowing for numerous crop seasons to occur throughout the entire year thanks to dependable watering. For instance, the building of waterways and dams throughout India was crucial to the nation's transformation from a net buyer of food to one that produces sufficient nourishment for itself during the era of the Green Revolution. These structures can also lessen the need for rain-fed agriculture by improving methods of farming while lowering the possibility of crop failures from drought. Additionally, dams can help current irrigation methods like drip systems become more widely used, which may improve performance & save water.[5] Relative to conventional watering techniques, drip irrigation maximizes the use of water as well as minimizes wastage by delivering water straight to the crop's roots. In times of surplus flow, like when it's raining, dams act as dams, holding water that is then released for use in agriculture during dry times. By offering a dependable and steady supply of clean water for agriculture, they lessen the effects of shortages and shifts in the seasons. Dams make it easier to move water to fields by creating canals, pipes, and other kinds of equipment that maintains the ideal amount of moisture for agricultural growth. Irrigation reservoir design takes into account various elements, including watershed subject matter, hydraulics, soil properties, and water from crops needs. The availability of water is determined by scientists using methods such as hydrological assessment and drainage simulation, and storage space is designed properly. To effectively control the release of water other transportation, dams are outfitted with barriers, valves, and other administrative systems. In addition to reducing transpiration as well as increasing the effectiveness of irrigation, operation and upkeep procedures guarantee the structural soundness and functioning of dam construction.

Benefits of Dam-Based Agricultural Supplies [6]

The irrigation supplies provided by dams supports agricultural regions in a number of ways, such as,

- Efficiency and harvest amounts are increased when farmers can plant crops that are valuable and expand their farming methods, which raises yields and revenues. This is made possible by a steady supply of freshwater.
- By guaranteeing steady and consistent harvests as well as lowering reliance on the precipitation and climate variations, irrigated from reservoirs helps to provide adequate nutrition.
- Better water supply systems boost local economies, generating jobs and improving living standards for growers as well as their households.
- Reservoir irrigation's effective management of water techniques decrease water waste and support environmentally friendly farming while protecting natural assets for future generations to inherit.

Obstacles and Things to Think About [7]

Although reservoirs are a vital source of agricultural water, they additionally resolve some issues and concerns, such as,

- **The effect on the environment:** Massive dam construction projects have the potential to cause destruction of habitat, imbalances in ecology, and changes in river circulation and species.
- **Social and financial ramifications:** constructing water barriers may force populations to be uprooted and incomes to be lost, necessitating extensive displacement and restoration plans.
- **Disputes over freshwater administration:** Rival requirements for water coming from different sectors, including homeowners, business, and farming, can result in disputes over the distribution and use of water, calling for strong governance and regulatory structures.

In result, dams are essential for providing water to irrigation systems, fostering growth in agriculture, and improving the availability of food. Even though they have many advantages, their development and maintenance require environmentally friendly approaches as well as careful assessment of environmental and social considerations.

Hydroelectric dams are able to support international efforts to attain food safety and ecological sustainability by utilizing technology improvements and putting good methods for handling water into practice.[8]

Hydro power generation

A renewable form of energy called hydroelectricity, sometimes referred to as hydro power, is produced by utilizing the momentum of water that moves. By building dams that hold water and control its discharge to run generators and generate electrical power, dams are essential to the production of hydroelectric. This essay examines the importance of hydroelectric generated by dams, covering its workings, advantages, difficulties, and potential. In order to help the area meet its requirement for energy, the structure of the dam generates electricity. Having consistent access to power promotes both commercial and production, which in turn promotes economic growth and job creation. Dams may produce water-powered electricity that is renewable and environmentally friendly, which is very helpful in fighting for global warming. Hydropower has an extensive history of use worldwide and is a dependable and established kind of energy from renewable sources.

Hydroelectric plants have the ability to preserve freshwater and produce power when needed, in contrast to wind and solar generation, both of which are intermittent sources of energy the fact that are dependent upon conditions.[9] In order to keep the power system reliable and stable as more flexible sources of renewable energy become available, dispatchability is essential. Hydroelectric power plants are able to swiftly adjust their output in response to variations in demand for power, guaranteeing a steady flow of energy. Hydroelectricity not only helps a country reduce its dependence on petroleum and coal and the air pollutants they cause, but it can also increase its energy independence by lowering its dependency on foreign fuels.

Hydroelectricity has comparatively low running and upkeep expenses, making it an affordable source of energy. Hydroelectricity more capable of producing baseload power—the steady stream of electrical supply which serves as the backbone of a power grid—than other alternative power resources. When opposed to conventional reservoirs, runof-river hydroelectric projects may have less of an effect on the environment because they redirect water sans building enormous lakes. Nevertheless, as will be covered in the next section, there can be serious environmental consequences to massive hydroelectric endeavors. By using dams to capture the inherent power of the water that flows, renewable energy that is clean may be produced. In order to optimize energy production, dams create dams and control the flow of water, which is a crucial part of this procedure.[10] Hydroelectric dams continue to be a vital part of the world's electrical grid notwithstanding their negative effects on the natural world, producing electricity that is sustainable and dependable for thousands of individuals globally.

Benefits

Energy from Renewable Source:

Because hydroelectricity uses the natural flow of water to generate power, it is both environmentally friendly and continuous. The melting snow and rain perpetually replenish hydroelectricity, in contrast to fossil fuels, which have a limited supply and are linked to warming temperatures.

Low Environmental Gas Pollutants:

When hydroelectricity is generated, fewer greenhouse gases are released into the atmosphere than when power plants powered by fossil fuels are used. This lowers the environmental impact associated with the production of power and helps slow down the impact of global warming. [11]

Dependable and Foreseeable:

Hydroelectricity generators are a dependable and consistent source of energy since they aren't affected by changes in fuel costs or outside variables like wind or sunshine. Because of its reliability, electricity from water is a reliable baseload energy source.

Electricity Storage:

In times of low demand, extra electricity can be stored in dams built by dams. Whenever there is a high need, the stored power can be granted liberty, giving the grid reliability and versatility in controlling the flow of energy.

Flood Regulate:

By holding extra water at times of high rain or melting snow, dams assist restrict river flow to minimize the risk of flooding. This lessens the risk of flood harming facilities crops, and towns below.

Water Supplies:

Hydroelectricity dams can be used for agriculture, civic use, and for business purposes, among other things. Particularly in times of flooding, intentionally releasing water from reservoirs guarantees an uninterrupted supply of water for a range of river uses.[12]

Drawbacks:

Environment Influence:

Building a reservoir or dam may have significant adverse effects on the natural world, destroying habitat, changing ecological systems, and upsetting fish movement designs, among other things.[13] In addition to dividing river ecosystems and lowering water quality, dams can have an effect on the diversity of aquatic life.

Socioeconomic Movement: Relocating villages is frequently necessary for the construction of reservoirs, which causes both cultural and social upheavals for the impacted people. People who have been excluded as well as native are especially susceptible to being uprooted and losing their homes and means of subsistence.

High Investment Prices: Hydroelectric generation projects are financial intensive due to the large initial outlay frequently needed to construct dams and water-power facilities. Over the course of the facility's existence, extra upkeep and operating expenses may accumulate to a considerable amount.

Limited Access to the Site: Not every geographical spot is appropriate for producing electricity from water. The increase of hydroelectricity may be hampered by the lack of appropriate locations for dam building due to variables like geography, geological sciences, and ecological limitations.

The process of sedimentation and Silting:

Reservoirs may fill with silt or sediment as time passes, decreasing their effectiveness and ability for retention. Additionally, sedimentation can shorten the service life of electrical facilities harm river habitats, and degrade the purity of water, thus requiring expensive cleaning and upkeep procedures.

Geographical Issues:

International challenges and disputes can arise from massive dam construction, particularly in international watersheds wherein several nations share water supply.[14] Difficulties over egalitarian shared benefits, downward effects, and entitlement to water have the potential to turn into geopolitical as well as ideological disputes.

Not with standing these limitations, dams that generate water power continue to be a significant source of renewable energy, supporting international efforts to cut carbon dioxide emissions and move toward an environmentally friendly energy environment. Thorough evaluation of considerations related to the environment, society, and economy is necessary to balance the benefits and downsides of hydroelectric endeavors

in order to promote positive and equal results for every stakeholder.

Flood Management

Dams are an essential tool for reducing flooding and safeguarding infrastructures and residents down.[15] The structures of dams may hold additional water during times that have significant precipitation or melting snow by controlling the rate of flow of rivers. The water may be gradually released when it has been collected, avoiding disastrous floods and embankment overrun. These structures' ability to regulate flooding may avoid fatalities, safeguard assets, and reduce monetary damages due to flooding. For instance, a number of dams were built in the Missouri River's watershed in the US as a consequence from the Flood Management and Water Management Act of 1936. After years of being notorious for its devastating hurricanes, the Missouri River currently experiences overflowing far less frequently and with less severity thanks to its extensive network of dams. In the same way, China's Three Gorges Reservoir was widely acknowledged for helping to lessen disaster across the Yangtze River, which is among the world's most susceptible to floods. It's crucial to take into account all possible disadvantages before utilizing reservoirs to prevent flooding, though. Big dams usually have a reservoir below them that holds an enormous quantity of water. This may restrict the amount of water available upstream for subsequent uses, including agriculture, business, and biological requirements, during protracted droughts. Effective dam operation requires striking the correct balance amongst the requirements for river water as well as the requirements in flood prevention.

Advantages of Flood Controlling Risk reduction [16]:

These structures lessen the possibility and intensity of floods down by controlling the flow of rivers or holding extra water. By doing this, precious assets, infrastructure, and neighborhoods are shielded from the loss and devastation caused by flooding.

Financial Savings:

By reducing the expenses of repairing flooding damage, responding to emergencies, and losing land and earnings, flood prevention efforts by dams can produce considerable financial savings. Constructions for flood management help impacted areas in the future.

Environmental Guarding:

By reducing the damaging effects of flooding on habitats in nature, dam-based control of flooding assists in preserving ecosystem and species. Riparian environments are resilient and healthy when river depths and flow rates are kept steady.

Difficulties and Aspects to Take into Account Sediments: As time passes, dams may retain silt and other particles, which lowers the storage capacity of the dams. The dredging as well as removal of sediment must be done on an ongoing basis to manage deposition and preserve the efficiency of the flood control system.

Reservoir Procedures:

It can be difficult to strike a balance between the opposing objectives of preventing flooding, ecological flows, power production, and access to water [17]. Public involvement, meticulous planning, and close collaboration are

necessary for optimal dam management.

Human and Ecological Effects: Building and maintaining reservoirs to reduce flooding may have adverse implications for society and the environment, such as uprooting neighborhoods, changing riverbank environments, and impairing down economies. It is necessary to tackle these effects via equitable process of planning and mitigation tactics in order to establish sustainable flooding prevention and control strategies.

In the end, holistic management of water resources relies heavily on reservoirs to prevent flooding because they offer vital safeguards from the destructive consequences of flooding. These structures improve security for communities, environmental long-term viability and adaptability by controlling flow in rivers, holding extra water, and reducing the likelihood of flooding. To handle obstacles and strike an equilibrium between conflicting demands, nevertheless, rigorous planning, funding, and administration are necessary for efficient control of floods. Reservoir construction can improve flood resistance while contributing to a safer and more environmentally friendly future via ongoing innovation and cooperation.

Findings

1. The Sholayar Dam significantly enhances water supply for agricultural and domestic use in Coimbatore district, contributing to improved crop yields and local livelihoods.

2. The dam has played a crucial role in maintaining ecological balance by regulating river flow and supporting local ecosystems, although it may also pose challenges to certain aquatic species.

3.The presence of the dam has stimulated Economic growth in Coimbatore district through increased agricultural productivity and the development of ancillary industries, such as fisheries and tourism.

4.While the dam has provided benefits, it has also led to displacement and changes in the livelihoods of some local communities, necessitating careful planning and rehabilitation efforts.

Suggestions

1. Implement advanced irrigation techniques and water conservation methods in the Coimbatore district to maximize the benefits of water supplied by the Sholayar Dam while ensuring sustainable use of resources.

2. Initiate awareness campaigns for local communities about the benefits and responsibilities associated with the dam's resources, promoting conservation and responsible usage of water.

3.Develop integrated projects that leverage the water supply from Sholayar Dam for agricultural development, local industries, and tourism, enhancing the overall Economic profile of Coimbatore district.

Conclusion

Located inside the Coimbatore region of Tamil Nadu, India, the Sholayar Reservoir is a tribute to the complex relationship that exists among earth's resources as well as human creativity. The hydroelectric dam has had a profound impact upon the economic status of the area during the many years since it was built, irreversibly altering the daily lives of those who live nearby. Built above its Chalakkudi River, the Sholayar Reservoir is an essential component of the area's

irrigation system. The dam is essential for agriculture, preventing flooding, power production, and meeting the drinking water demands in the region of Coimbatore. Because of its massive existence, the region around it has changed, creating a reservoir which is essential to natural as well as human societies. There are numerous and extensive socio-economic benefits associated with the Sholayar Reservoir. First, by regulating water supply, the reservoir has increased the production of agriculture within Coimbatore Region, enabling producers to grow crops throughout the year as well as vary their farming methods. As a result, there has been a decrease in rural impoverishment, a rise in agriculture revenue, and stimulation of investment in the economy.

Evaluating the socioeconomic impacts of the construction of Sholayar Reservoir in the region of Coimbatore entails examining a number of variables, including neighborhood populations, jobs, tourism, drinking water, as well as farming.

Reference

[1] Schmitt, R. J. P., & Rosa, L. (2024). Dams for hydropower and irrigation: Trends, challenges, and alternatives. *Renewable and Sustainable Energy Reviews*, *199*, 114439.

[2] George, F. E. (2020). *Assessment of agricultural loss due to 2018 flood to farm households in the flood pains of Chalakudy river* (Doctoral dissertation, Department of Agricultural Economics, College of Horticulture, Vellanikkara).

[3] Fossi, M. C., Vlachogianni, T., Galgani, F., Degli Innocenti, F., Zampetti, G., & Leone, G. (2020). Assessing and mitigating the harmful effects of plastic pollution: the collective multi-stakeholder driven Euro Mediterranean response. *Ocean & coastal management*, *184*, 105005.

[4] Karuppasamy, M. K., & Arunachalam, M. (2023). Species diversity, distributions and conservation implications of Ichthyofauna of hill streams of Anamalai Tiger Reserve, Southern Western Ghats, India.

[5] Sampedro Sánchez, D. (2022). Can Irrigation Technologies Save Water in Closed Basins? The effects of Drip Irrigation on Water Resources in the Guadalquivir River Basin (Spain).

[6] Singh, N. K., & Rai, A. K. (2024). Redefining Sustainable Agriculture for the 21st Century by Vertical Farming. *Journal of Scientific Research and Reports*, *30*(5), 510-525.

[7] Alla, Y. M. K., & Liu, L. (2021). Impacts of dams on the environment: a review. *International Journal of Environment, Agriculture and Biotechnology*, *6*(1)

[8] Quaranta, E., Bejarano, M. D., Comoglio, C., Fuentes-Pérez, J. F., Pérez-Díaz, J. I., Sanz-Ronda, F. J., ... & Tuhtan, J. A. (2023). Digitalization and real-time control to mitigate environmental impacts along rivers: Focus on artificial barriers, hydropower systems and European priorities. *Science of the Total Environment*, *875*, 162489.

[9] Pali, B. S., & Vadhera, S. (2021). A novel approach for hydropower generation using photovoltaic electricity as driving energy. *Applied Energy*, *302*, 117513.

.[10] Mamassis, N., Efstratiadis, A., Dimitriadis, P., Iliopoulou, T., Ioannidis, R., & Koutsoyiannis, D. (2021). Water and energy. In *Handbook of Water Resources Management: Discourses, Concepts and Examples* (pp. 619-657). Cham: Springer International Publishing

[11] Bilgili, F., Lorente, D. B., Kuşkaya, S., Ünlü, F., Gençoğlu, P., & Rosha, P. (2021). The role of hydropower energy in the level of CO2 emissions: An application of continuous wavelet transform. *Renewable Energy*, *178*, 283-294.

[12] Kron, W., Tingsanchali, T., Loucks, D. P., Renaud, F. G., Bogardi, J. J., & Fekete, A. (2021). Water related hazard and risk management. In *Handbook of Water Resources Management: Discourses, Concepts and Examples* (pp. 675-734). Cham: Springer International Publishing.

[13] Jawad, L. A. (2021). Impacts of Dams on Aquatic Biodiversity, Fisheries, Fishes and Their Environment: Problems that Could Be Present in Iraq with Recommendations. *Tigris and Euphrates Rivers: Their Environment from Headwaters to Mouth*, 369-382.

[14] Kumar Sinha, A., Johari, S., Jha, K. N., & Singh, A. (2020). Unique solutions for challenging riparian disputes. *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, *12*(4), 03720003.

[15] Pregnolato, M., Han, D., Jacomo, A. L., De Risi, R., Agarwal, J., & Huang, J. (2021). Resilient infrastructures for reducing urban flooding risks. *AND SUSTAINABLE WATER SYSTEMS*, 181.

[16] Ward, P. J., de Ruiter, M. C., Mård, J., Schröter, K., Van Loon, A., Veldkamp, T., ... & Wens, M. (2020). The need to integrate flood and drought disaster risk reduction strategies. *Water Security*, *11*, 100070.

[17] Karakatsanis, D., Patsialis, T., Kalaitzidou, K., Kougias, I., Ntona, M. M., Theodossiou, N., & Kazakis, N. (2023). Optimization of Dam Operation and Interaction with Groundwater: An Overview Focusing on Greece. *Water*, *15*(21), 3852

A Study on Changes in the Slope of the Phillips Curve in USA and Brazil : Empirical Evidence from 1995 to 2020.

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Abstract
This research investigates the evolving relationship between inflation and unemployment in the USA and Brazil from 1995 to 2020 using quarterly time-series data, with a particular focus on the dynamics of the Phillips Curve. By employing Time-Varying Regression, we analyze how this relationship changes. In the USA, our study identifies key factors such as savings, technological advancements, and GDP per capita that influence these economic variables, revealing a trend toward a Flattening Phillips Curve. This indicates that traditional monetary policy tools may need to be re-evaluated, as the responsiveness of unemployment to inflation has diminished. Conversely, in Brazil, we observe a positive correlation between inflation and unemployment, contrary to the traditional inverse Phillips Curve. This relationship is influenced by factors like oil prices and inflation expectations. Our findings suggest that Brazil's economic policy should focus on stabilizing inflation expectations and addressing supply-side constraints to manage the inflation-unemployment trade-off effectively. This study underscores significant regional differences in the economic behavior of developed and developing countries. It contributes to the broader discourse on economic policy by highlighting the need for approaches to managing inflation and unemployment. Policymakers in the USA should consider the diminishing impact of inflation on unemployment, while those in Brazil should address the unique factors driving their inflation-unemployment dynamics.
Keywords: United states, Brazil, Flattening Phillips Curve, inflation, unemployment

1. Introduction

Inflation and unemployment are crucial measures of a country's economic health. Inflation indicates how much prices for goods and services are rising, reducing how much people can buy with their money. Meanwhile, unemployment represents the percentage of people in the labor force who are actively looking for work. Low rates of both are vital for strong economic growth and overall stability.

Historically, economic theories suggested a trade-off between inflation and unemployment, initially observed by William Phillips in the UK [1], and later extended by economists like Paul Samuelson and Robert Solow in the US [2]. However, this relationship has been challenged, particularly during the 1970s when high inflation and high unemployment occurred simultaneously, a phenomenon known as stagflation.

More recent discussions, such as a 2019 article from the Economist [3], introduce the concept of a "Flattening Phillips Curve". This idea suggests that the relationship between unemployment and inflation has weakened, with the curve becoming almost flat in recent years. This change suggests that the two economic indicators are less connected than before.

Further research, including studies by Murphy [4] and Çiçek [5], shows that the Phillips Curve still exists but its dynamics are influenced by modern factors like globalization and technological advancements. Recent analyses by Hazell,

Herreno et al. [6], and Federal Reserve Bank of St. Louis [7], also emphasize the significant role of inflation expectations in shaping the Phillips Curve recently.

A Time-Varying model is crucial for capturing the dynamic nature of the relationship between inflation and unemployment, accommodating changes in economic conditions, non-linear relationships, and external shocks. Historical data, such as the challenges presented by stagflation in the 1970s, demonstrate the inadequacy of static models. More recent research, including studies by Hazell et al. [6] and Beaudry et al. [8], highlights the influence of modern factors like globalization, technological advancements, and shifting inflation expectations. These models provide policymakers with accurate, real-time insights necessary for effective economic decision-making in a rapidly evolving global economy.

In this study, The USA and Brazil are chosen for their contrasting economic environments. The USA, as a developed economy, and Brazil, as a developing one, offer a diverse comparative framework to study how factors like production gaps, inflation expectations, and oil prices impact inflation and unemployment. This comparison provides insights for economic policies to different development stages.

This research compares how these dynamics manifest in the distinct economic environments of the USA and Brazil from 1995 to 2020. It aims to uncover how different influences, such as production gaps, inflation expectations, savings, GDP per capita, total factor productivity, and oil prices, affect the inflation-unemployment relationship in these countries using advanced regression models. By understanding these relationships, this study provides insights that can help tailor economic policies more effectively for both developed and developing countries, reflecting the complexities of modern economic realities.

2. Literature Review

2.1 Studies on the Existence of the Phillips Curve

The stagflation of the 1970s, revealing a positive correlation between inflation and unemployment, prompted renewed examination of the Phillips Curve. This renewed interest is evidenced by the study by Gruen et al. [9], who affirmed the Phillips Curve in Australia using a VAR model with data from 1965 to 1997. Similarly, in smaller economies such as Northern Cyprus, ARDL and ECM models displayed enduring relationships both short-term and long-term [10]. In contrast, Hindrayanto et al. [11] identified that within the EU, this relationship is only short-term, while Vermeulen [12] observed a transient positive correlation in South Africa that eventually reversed over the long term.

2.2 The Flattening Phillips Curve

The notion of the 'Flattening Phillips Curve' indicates a weakening linkage between inflation and unemployment, especially notable in EU studies, where the correlation has nearly disappeared in countries like Germany [13]. Murphy [4]'s research aligns with this finding, attributing the diminishing slope to globalization, e-commerce activities, and demographic changes. This observation is further supported by the works of Çiçek [5], Hazell et al. [6], and Beaudry et al. [8], all noting a gradual decline in the curve's slope over time. Additionally, the Bank of Thailand has noted a similar reduction in the curve's steepness in both the U.S. and the EU from the late 1990s to the late 2010s [14].

2.3 Factors Influencing the Relationship between Inflation Rates and Unemployment

The dynamics between inflation rates and unemployment are profoundly influenced by various factors, each playing a pivotal role in modulating the Phillips Curve's slope. Studies like Murphy [4] highlight that globalization has significantly contributed to the flattening of the Phillips Curve, underscoring the impact of increasing global interconnectivity on

traditional economic patterns. Çiçek's [5] analysis using the Time-Varying Process (TVP) model further supports this, illustrating how domestic and global output gaps have contributed to a more pronounced flattening of the Phillips Curve in Turkey.

Iakova's [15] observations reiterate the influence of global economic integration on flattening the Phillips Curve across various economies. Additional research by Hazell et al. [6], alongside Beaudry et al. [8], points to the significant role of inflation expectations in moderating the Phillips Curve's steepness. These expectations, when entrenched in economic decision-making, can trigger self-fulfilling inflationary cycles, where preemptive price and wage increases by businesses and consumers drive inflation up, confirming their initial forecasts.

Technological advancements and automation, as discussed by McAdam et al. [16] and Murphy [4], also change the employment landscape, diminishing labor demand in certain sectors and thus influencing the unemployment-inflation interaction. The Bank of Thailand corroborates these findings, noting that higher savings rates and aging populations lead to reduced consumer spending, thereby easing inflationary pressures and contributing to a flatter Phillips Curve [14].

3. Data

The inflation rate serves as the dependent variable, while the unemployment rate acts as the independent variable. It also studies additional factors influencing this relationship, such as production gaps, inflation expectations, savings, GDP per capita, total factor productivity, and oil prices. The study utilizes quarterly time-series data spanning from 1995 to 2020 for both the United States and Brazil, sourced from Federal Reserve Economic Data, Thomson Reuters, and World Bank databases.

Table 1: Illustrates the coefficients used in the study.

Variables (units)	Explanations
Inflation rates (%)	The measurement of changes in the general price level of goods and services within a country over a period, expressed as a percentage compared to the price level in a previous period.
Domestic Production Gaps (%)	The measurement of the difference between a country's current level of production and its potential maximum production using available resources. Measuring this production gap helps understand the current state of the economy.
Inflation Expectation rates (%)	The forecast or assessment of the increases in level and trend of future price in the overall economy.
Savings ($)	The total savings in the economy of a country, including savings by the government and private sectors, as well as external context.
Gross Domestic Product per Capita (%)	The growth rate of Gross Domestic Product (GDP) in a country, expressed as a percentage of the total population of that country.
Total Factor Productivity (%)	The growth rate of Total Factor Productivity (TFP) in a country's economy indicates the efficiency of production derived from using all available resources.
Crude oil price ($/bbl.)	The price of crude oil in the global market.

4. Methodology

This study employs time series data and utilizes the concept of time-varying coefficients. Specifically, a Time-Varying Regression model is used to estimate

coefficients that vary over time, analyzing the relationship between inflation rates (dependent variable) and unemployment rates (independent variable). Subsequently, a Multiple Linear Regression model examines various factors influencing this relationship. Moreover, a significance level of 0.1 will be used to determine statistical significance. The details are as follows:

4.1 Time-Varying Regression Model

The study estimates Time-Varying Coefficients using a Time-Varying Regression model to analyze the relationship between inflation rates and varying unemployment rates. Inflation rates are considered the dependent variable, while unemployment rates serve as the independent variable. This analysis spans both the United States and Brazil. The Time-Varying Regression equation is formulated as:

$$Inf_t = \beta_{0,i,t} + \beta_{1,t}(Unemp)_t + v_t \quad (1)$$

$$\beta_{0,t} = G_t\beta_{0,t-1} + \xi_t \quad (2)$$

$$\beta_{1,t} = I_t\beta_{1,t-1} + \varsigma_t \quad (3)$$

; where Inf_t is the Time-Varying inflation rate (t), $Unemp_t$ is the Time-Varying unemployment rate (t), $\beta_{0,t}$ is the Time-Varying parameters in the equation for Time-Varying constants, $\beta_{1,t}$ is the Time-Varying parameters in the equation for Time-Varying unemployment rate, v_t is the random error, G_t is the parameter used to explain the Time-Varying changes of $\beta_{0,t}$ over time, ξ_t is the random term in the estimated State Equation Error, I_t is the parameter used to explain the Time-Varying changes of $\beta_{1,t}$ over time, ς_t is the random term in the estimated State Equation Error.

4.2 Multiple Linear Regression Model

The study examines factors influencing changes in the slope of the Phillips curve through Multiple Linear Regression. Separate equations are estimated for each country both the United States and Brazil where coefficients vary with changes in the unemployment rate as the dependent variable. Independent variables include production gaps, inflation expectation, savings, GDP per capita, total factor productivity, and oil prices. The equations are specified as follows:

$$\beta_{1,t} = \lambda + \theta_1(DomesGap_t) + \theta_2(EInf_t) + \theta_3(S_t) + \theta_4(GDPcap_t) + \theta_5(TFP_t) + \theta_6(Oil_t) + u_t \quad (4)$$

; where $\beta_{1,t}$ is the coefficient of the relationship between unemployment rate and inflation, λ is the constant term, $\theta_1, \theta_2, \theta_3, \theta_4, \theta_5, \theta_6$ are the coefficients of the independent variables in the order of $DomesGap_t$, $EInf_t$, S_t, $GDPcap_t$, TFP_t, Oil_t, $DomesGap_t$ is the production gap in the country that changes over time (t), $EInf_t$ is the Time-Varying inflation forecast (t), S_t is the Time-Varying savings (t), $GDPcap_t$ is the GDP per capita that changes over time (t), TFP_t is the Total Factor Productivity (TFP) that changes over time (t), Oil_t is the crude oil price that changes over time (t), u_t is the error term observed at time t.

5. Result

5.1 Results of the study on Time Varying Regression

Table 2 presents the Time-Varying Coefficients of the unemployment rate in both the United States and Brazil. The study results show that the data follow a normal distribution, with a relatively low variance. Therefore, the mean is the most appropriate measure for explaining the relationship between the unemployment rate and the inflation rate in this analysis.

From Table 2, notable distinctions are observed in the relationship between the unemployment and inflation rates in the United States and Brazil. For the mean of the parameter, in the United States, a 1% increase in the unemployment rate correlates with a 0.118% decrease in the inflation rate, whereas in Brazil, the same increase in unemployment

corresponds to a 0.036% increase in inflation. These findings highlight significant differences in the variables influencing each country's economic dynamics.

Table 2: Illustrates the coefficients of the unemployment rate in the United States and Brazil.

	USA		Brazil	
	$\beta_{0,USA}$	$\beta_{1,USA}$	$\beta_{0,Brazil}$	$\beta_{1,Brazil}$
Minimum value	3.698	-0.466	-1.567	-2.039
1st Quartile	4.453	-0.246	3.049	-0.488
Median	4.708	-0.146	4.305	0.180
Mean	4.654	-0.118	4.028	0.036
3rd Quartile	4.921	0.002	5.278	0.380
Maximum value	5.438	0.349	8.445	2.472
Pseudo R-squared	0.999		0.9996	

The Phillips Curve theory traditionally suggests an inverse relationship between inflation and unemployment rates, implying that as unemployment rises, inflation should decrease, and vice versa. However, the study's results for Brazil reveal a positive correlation between unemployment and inflation rates, suggesting that both variables tend to move in the same direction. This finding challenges the traditional understanding of the Phillips Curve's relationship between unemployment and inflation in Brazil.

Figure 1 The coefficients of the relationship between inflation rates and unemployment rates that vary over time for the United States and Brazil.

Figure 1 illustrates time-varying coefficients of unemployment rates from 1995 to 2020, comparing trends between the United States and Brazil. The coefficient for the United States reveals a relatively flat pattern, resembling a Flattening Phillips Curve, approaching zero. This suggests a minimal correlation between inflation and unemployment in the United States over the studied period.

Moreover, the coefficients for Brazil depict a downward-sloping curve, aligning to the traditional Phillips Curve theory with a convex shape towards the origin. However, since 2012, there has been an observed positive relationship between inflation and unemployment rates in Brazil, contradicting traditional theory.

To extend more, during this period, the sharp rise in crude oil prices led to increased production and transportation costs, which in turn raised the prices of goods and services, resulting in higher inflation in Brazil. Simultaneously, business owners began to anticipate potentially higher future inflation, directly affecting investment decisions and pricing strategies. Consequently, businesses prepared by scaling back investments, ultimately leading to an increase in unemployment rates.

As a developing country, Brazil faces stagflation more frequently than developed nations like the United States. This is evident in the coefficient (β_1) for Brazil, which

frequently shows a positive value compared to the United States, where β_1 is positive but less frequently. This highlights Brazil's greater sensitivity to changes in inflation rates compared to the more stable economy of the United States.

5.2 Results of Multiple Linear Regression

The study investigates factors influencing the coefficient of the significant relationship between inflation rates and changing unemployment, as indicated by the p-value. The coefficient itself acts as the dependent variable, while independent variables include production gaps, expected inflation, savings, gross domestic product per capita, total factor productivity, and oil prices.

Table 3 illustrates factors influencing the coefficient of the relationship between inflation rates and changing unemployment.

Coeff	USA	Brazil
	Estimate (Std. Error)	**Estimate (Std. Error)**
Intercept	-0.3570 (3.4615)	-2.9394 (14.3482)
Domestic Gap	-0.0187 (0.1115)	0.0109 (0.0947)
Expected Inflation	0.0650 (0.0926)	0.5732*** (0.1666)
Saving	-0.4748* (0.2126)	0.3637 (0.8382)
GDP per cap	1.2787** (0.4353)	-0.5693 (0.7810)
TFP	-3.0470* (1.4269)	-2.1521 (1.3220)
Oil	-0.0300 (0.0583)	-0.6016* (0.3175)

Note: 1. Values in parentheses is standard errors.
2. "*" Statistically significance at 0.10
"**" Statistically significance at 0.05
"***" Statistically significance at 0.01

Table 3 illustrates significant factors influencing changes in the coefficient of the relationship between inflation rates and changing unemployment over time in both the United States and Brazil.

In the United States, savings, GDP per capita, and total factor productivity are the significant factors. It can be observed that:

- **Savings:** An increase of 1% in savings correlates with a reduction of approximately 0.47% in the coefficient of the relationship between inflation and unemployment. This indicates that higher savings reduce the impact of unemployment on inflation, aligning with findings from Mankiw et al. [17] on the inverse relationship between household saving rates and inflation. Increasing savings helps alleviate domestic consumption pressures, as individuals opt to save money in banks rather than invest or purchase goods. This results in a reduction in aggregate demand, hence reducing pressures on inflation accordingly.
- **Total Factor Productivity:** A 1% increase in technological development leads to approximately a 3.05% decrease in the impact of unemployment on inflation. This demonstrates technology's role in enhancing efficiency and productivity, thereby reducing the inflationary pressures and flattening the Phillips Curve, which is similarly concluded by the IMF and Forbes et al. [18].
- **GDP per Capita:** Conversely, a 1% increase in GDP per capita corresponds to a 1.28% increase in the coefficient of the relationship between inflation and unemployment. This suggests that higher income levels increase the influence of

unemployment on inflation, aligning with the aggregate demand theory.

In summary, savings, technology, and GDP per capita are critical factors influencing changes in the coefficient of the relationship between inflation and unemployment over time in the United States. Savings and technology reduce the impact of unemployment on inflation, whereas GDP per capita enhances it, each affecting the dynamics of inflation and unemployment differently.

In Brazil, expected inflation and oil prices are significant factors influencing changes in the coefficients of the relationship between inflation and unemployment over time:

- **Expected Inflation:** A 1% increase in expected inflation correlates with a 0.57% increase in the unemployment rate's coefficient, indicating that higher expected inflation intensifies the impact of unemployment on inflation. This aligns with the inflation expectations theory and the New Keynesian model suggesting that anticipated inflation leads to immediate wage demands and price increases, contributing to inflationary pressures. Businesses may raise prices, further increasing inflationary pressures and potentially increasing unemployment rates due to higher labor costs.
- **Oil Prices:** Conversely, a 1% rise in oil prices results in a decrease of approximately 0.60% in the unemployment rate's coefficient. Higher oil prices elevate production costs, potentially delaying hiring and increasing unemployment rates, thereby increasing inflationary pressures, in line with the cost of capital Theory. Therefore, as oil prices rise, the relationship between inflation rates and unemployment rates tends to flatten, reflecting a flatter Phillips curve.

In summary, savings, technology, and GDP per capita are critical factors shaping the relationship between inflation and unemployment in the United States. Savings and technology mitigate the impact of unemployment on inflation, while GDP per capita enhances it. In contrast, in Brazil, expected inflation and oil prices significantly influence this relationship, with expected inflation exacerbating the impact of unemployment on inflation, and higher oil prices reducing it. These factors contribute to the dynamics of inflation and unemployment, demonstrating distinct economic conditions in each country.

6. Conclusion

Inflation and unemployment are essential indicators of economic health, traditionally perceived to share an inverse relationship, as depicted by the Phillips Curve. Recent evidence, however, suggests that this relationship has evolved, particularly in developed regions such as the United States and Europe, where the Phillips Curve appears to be flattening. This change indicates a weakening connection between inflation and unemployment, diverging from historical norms.

This research aimed to analyze the dynamic interplay between inflation and unemployment within two distinct economic settings— the United States and Brazil—from 1995 to 2020. Employing Time-Varying and Multiple Linear Regression models, the study explored how various factors such as savings, technological advancements, and GDP per capita influence this relationship. Our findings indicate a significant shift toward a Flattening Phillips Curve in the United States,

suggesting a diminishing influence of unemployment on inflation. This trend points towards a potential decoupling of these two critical economic variables. Key factors like enhanced savings and technological efficiency have been instrumental in reducing inflation's sensitivity to unemployment fluctuations. Conversely, in periods of low unemployment, GDP per capita appears to increase inflation's sensitivity, leading to a more pronounced convex Phillips Curve.

In contrast, the Brazilian context revealed a deviation from the expected negative correlation between inflation and unemployment. The analysis from 1995 to 2020 shows an initial inverse relationship, which shifted to a positive correlation post-2012, influenced by factors like economic growth, which boosted labor demand and reduced unemployment, alongside rising domestic consumption and relaxed monetary policies that heightened inflationary pressures.

The study identifies expected inflation and oil prices as significant factors influencing the Phillips Curve in Brazil, with higher oil prices mitigating inflation's response to unemployment changes. This suggests a more complex interaction between economic policies and market conditions in Brazil compared to the United States.

In conclusion, this research provides valuable insights into the evolving dynamics of inflation and unemployment, contributing to more effective economic policy formulation. By understanding these intricate relationships, policymakers can better tailor interventions to the unique economic conditions of both developed and developing nations, enhancing economic stability and growth.

Acknowledgements

I would like to express my heartfelt thanks to Associate Professor Dr. Paravee Maneejuk, Associate Professor Dr. Woraphon Yamaka and Dr. Worrawat Saijai for their outstanding guidance and mentorship during this research. Their knowledge and insights were crucial in shaping the analytical direction and maintaining the academic rigor of this study. Their dedication to excellence not only enriched this work but also significantly helped in my academic and professional growth.

I am also grateful for the ongoing support and resources from the Department of Economics at Chiang Mai University, which were essential in facilitating this research.

References

[1] Phillips, A. W. (1958). The relation between unemployment and the rate of change of money wage rates in the United Kingdom, 1861–1957. Economica, 25(100), 283-299.

[2] Samuelson, P. A., & Solow, R. M. (1960). Analytical aspects of anti-inflation policy. American Economic Review, 50(2), 177-194.

[3] The Economist. (2019), May 24. The flattening Phillips curve. Retrieved January 5, 2023, from https://www.economist.com/special-report/2019/10/10/economists-models-of-inflation-are-letting-them-down

[4] Murphy, A. (2018). The death of the Phillips curve? Working Paper No. 1801. Federal Reserve Bank of Dallas, 1-9.

[5] Çiçek, S. (2012). Globalization and flattening of Phillips curve in Turkey between 1987 and 2007. Economic Modelling, 29(5), 1655-1661.

[6] Hazell, J., Herreno, J., Nakamura, E., & Steinsson, J. (2022). The slope of the Phillips Curve: Evidence from U.S. states. The Quarterly Journal of Economics, 137(3), 1299-1344.

[7] Federal Reserve Bank of St. Louis. (2021, July 15). Inflation expectations, the Phillips Curve, and the Fed's dual mandate. Page One Economics. Retrieved January 5, 2024, from https://research.stlouisfed.org/publications/page1-econ/2021/07/15/inflation-expectations-the-phillips-curve-and-the-

feds-dual-mandate
[8] Beaudry, P., Galizia, D., & Portier, F. (2020). Putting the cycle back into business cycle analysis. American Economic Review, 110(1), 1–47.
[9] Gruen, D., Pagan, A., & Thompson, C. (1999). The Phillips curve in Australia. Journal of Monetary Economics, 44(2), 223-258.
[10] Islam, F., Shahbaz, M., & Shabbir, M. (2011). Phillips curve in a small open economy: A time series exploration of North Cyprus. Journal of Economic Studies, 38(6), 688-705.
[11] Hindrayanto, I., Samarina, A., & Stanga, I. M. (2019). Is the Phillips curve still alive? Evidence from the euro area. Economics Letters, 174, 149-152.
[12] Vermeulen, J. C. (2017). Inflation and unemployment in South Africa: Is the Phillips curve still dead? Southern African Business Review, 21(1), 20-54.
[13] Liargovas, P., & Psychalis, M. (2022). Phillips Curve: The Greek Case. European Review, 30(2), 244-261.
[14] Bank of Thailand. (2020, June 19). Factors affecting the Thai economy through economic measures from COVID-19: Case studies of the USA and the Eurozone. Frequently Asked Questions. Retrieved January 17, 2024, from https://content.botlc.or.th/mm-info/BOTCollection/BOTFAQ/FAQ170.pdf
[15] Liargovas, P., & Psychalis, M. (2022). Phillips Curve: The Greek Case. European Review, 30(2), 244-261.
[16] McAdam, P., & Willman, A. (2013). Technology, utilization, and inflation: What drives the new Keynesian Phillips curve? Journal of Money, Credit and Banking, 45(8), 1547-1579.
[17] Ball, L., & Mankiw, N. G. (2002). The NAIRU in theory and practice. Journal of Economic Perspectives, 16(4), 115-136.
[18] Forbes, K., Reinhardt, D., & Wieladek, T. (2017). The spillovers, interactions, and (un)intended consequences of monetary and regulatory policies. Journal of Monetary Economics, 85, 1-22.

An Analysis of the Asymmetric correlation between Bitcoin and other financial assets.

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Abstract

This study analyzes the asymmetric relationships and causality between Bitcoin and other financial assets, such as gold, the S&P 500 index, and green bonds. It utilizes weekly time series data spanning 12 years. The study employs Quantile Vector Autoregression and Quantile Granger Causality. The findings reveal that the relationships between Bitcoin and other assets vary across different market conditions. Bitcoin and gold exhibit a positive relationship, particularly during bearish markets. The relationship with the S&P 500 index is significant across all market conditions but tends to weaken in bullish markets. Green bonds demonstrate a positive relationship with Bitcoin, especially in bullish markets. The causality analysis indicates that gold significantly influences Bitcoin during bearish markets, while the S&P 500 index affects Bitcoin during severe bear markets and stable market conditions. Green bonds show a significant relationship with Bitcoin exclusively during stable markets. These results have important implications for investment decision-making and portfolio risk management, particularly during periods of high market volatility. The study also offers policy recommendations to foster efficient and sustainable investment practices.

Keywords: Quantile Vector autoregression, Quantile Granger Causality, Bitcoin, Gold, S&P500, Green Bond

1. Introduction

As a leading digital currency, Bitcoin has become a significant topic in financial studies due to its properties as both a speculative asset and a potential hedge (Dyhrberg, 2016). Gold, on the other hand, maintains its status as a safe-haven asset, playing a crucial role in portfolio risk diversification (Baur and McDermott, 2010). The S&P 500 index represents the stock market, reflecting the overall U.S. economy and influencing global capital markets (Rapach et al., 2013). Green bonds are financial instruments with an increasing role in raising funds for environmental projects and are crucial for sustainable development (Flammer, 2021). Furthermore, including green bonds in the analysis will help understand the role of sustainable finance in the context of the overall financial market (Reboredo, 2018).

In the increasingly volatile and complex global financial markets, understanding the relationships between assets with different characteristics is crucial for effective market analysis and risk management (Baur and Lucey, 2010). This research focuses on analyzing the asymmetric relationships between Bitcoin, gold, the S&P 500 index, and green bonds - all of which play significant roles in today's financial markets. We employ econometric methods, namely Quantile Vector Autoregression and Quantile Granger Causality, to examine these asymmetric relationships and causalities.

Studying the asymmetric relationships

between these assets is important for several reasons. First, asymmetry in asset relationships can have a significant impact on risk diversification and portfolio efficiency (Ang and Chen, 2002). Second, understanding how assets behave in different market conditions can help develop more effective investment strategies (Longin and Solnik, 2001). Third, analyzing relationships between assets with different characteristics can help us understand how volatility is transmitted between markets (Diebold and Yilmaz, 2012).

The results of this research are expected to enhance our understanding of modern financial market dynamics. This will benefit investors, fund managers, and policymakers in developing more effective investment strategies and risk management approaches. Furthermore, it will contribute to the design of financial policies and market regulations that are suitable for an increasingly complex financial environment.

2. Data

This research utilizes weekly time-series data covering a 12-year period, from May 2013 to March 2024. The data includes four variables: Bitcoin price, gold price, the S&P 500 index, and green bonds. The data is transformed into logarithmic differences (dln) to ensure stationarity at the I(0) level. This results in four new variables: Bitcoin growth rate (dlnBTC), gold price growth rate (dlnGOLD), S&P 500 index growth rate (dlnSPX), and green bond growth rate (dlnGREEN).

3. Methodology

Quantile Vector Autoregression (QVAR) is employed to analyze the asymmetric relationships between Bitcoin and other financial assets. This method examines variable relationships across all quantile levels, considering both upper and lower distributions of the data. It reveals the dynamic nature of relationships at each quantile level, especially during periods of heightened market volatility.

Cecchetti and Li (2008) provided a simple minimum QVAR process for ordering command p, considering an M-dimensional vector of variables where an M-dimensional vector of variables is considered. $Y_t = (y_{1t}, \ldots, y_{M_t}$ for $t = t, \ldots, T$ In general theory, we can write it in a general form as:

$$Y_t = A_0^\tau + A_1^\tau Y_{t-1} + \; + A_p^\tau y_{t-p} + u_t^\tau,$$

Where: A_0^τ is the vector of intercepts at quantile $\tau = [0, 1]$

A_p^τ is $(M \times M)$ matrix lagged coefficients at quantile τ

μ_t is the vector of error terms that are assumed to have an asymmetric distribution and a time-invariant covariance matrix(Σ) . For example, consider a four-variable QVAR model:

$$\begin{pmatrix} y_{BTCt} \\ y_{GOLDt} \\ y_{SPXt} \\ y_{GREENt} \end{pmatrix} = \begin{pmatrix} A^\tau_{BTC_0} \\ A^\tau_{GOLD_0} \\ A^\tau_{SPX_0} \\ A^\tau_{GREEN_0} \end{pmatrix} + \begin{pmatrix} A^\tau_{BTCBTC} & A^\tau_{BTCGOLD} & A^\tau_{BTCSPX} & A^\tau_{BTCGREEN} \\ A^\tau_{GOLDBTC} & A^\tau_{GOLDGOLD} & A^\tau_{GOLDSPX} & A^\tau_{GOLDGREEN} \\ A^\tau_{SPXBTC} & A^\tau_{SPXGOLD} & A^\tau_{SPXSPX} & A^\tau_{SPXGREEN} \\ A^\tau_{GREENBTC} & A^\tau_{GREENGOLD} & A^\tau_{GREENSPX} & A^\tau_{GREENGREEN} \end{pmatrix} \begin{pmatrix} y_{BTCt-1} \\ y_{GOLDt-1} \\ y_{SPXt-1} \\ y_{GREENt-1} \end{pmatrix} + \begin{pmatrix} u^\tau_{BTCt} \\ u^\tau_{GOLDt} \\ u^\tau_{SPXt} \\ u^\tau_{GREENt} \end{pmatrix},$$

Therefore, the structure of the error term can be written as follows:

$$\Sigma = \begin{bmatrix} u^\tau_{BTCt}u^\tau_{BTCt} & u^\tau_{BTCt}u^\tau_{GOLDt} & u^\tau_{BTCt}u^\tau_{SPXt} & u^\tau_{BTCt}u^\tau_{GREENt} \\ u^\tau_{GOLDt}u^\tau_{BTCt} & u^\tau_{GOLDt}u^\tau_{GOLDt} & u^\tau_{GOLDt}u^\tau_{SPXt} & u^\tau_{GOLDt}u^\tau_{GREENt} \\ u^\tau_{SPXt}u^\tau_{BTCt} & u^\tau_{SPXt}u^\tau_{GOLDt} & u^\tau_{SPXt}u^\tau_{SPXt} & u^\tau_{SPXt}u^\tau_{GREENt} \\ u^\tau_{GREENt}u^\tau_{BTCt} & u^\tau_{GREEN}u^\tau_{GOLDt} & u^\tau_{GREENt}u^\tau_{SPXt} & u^\tau_{GREENt}u^\tau_{GREENt} \end{bmatrix}$$

Where $u^\tau_{BTCt}u^\tau_{BTCt} = \sigma_{BTCBTC} = Var(u_{BTCt})$, $u^\tau_{it}u^\tau_{jt} = Cov(u^\tau_{jt}u^\tau_{jt})$, $u^\tau_{SPXt}u^\tau_{SPXt} = Var(u^\tau_{SPXt}) = \sigma_{SPXSPX}$

After using QVAR to analyze the asymmetric relationships between Bitcoin and other financial assets, we will use Quantile Granger Causality to analyze the causal relationships between Bitcoin, gold, S&P500, and green bonds. This will be done by estimating the two-dimensional conditional quantile function, which can be shown as follows:

$$\begin{pmatrix} Q(\tau)(BTC_t|(BTC, GOLD)_{t-1} \\ Q(\tau)(GOLD_t|(BTC, GOLD)_{t-1} \end{pmatrix} = \begin{pmatrix} \alpha_0(\tau) \\ \alpha_1(\tau) \end{pmatrix} + \begin{pmatrix} \sum_{j=1}^{p} \gamma_{0j} BTC_{t-j} \\ \sum_{j=1}^{p} \gamma_{1j} GOLD_{t-j} \end{pmatrix} + \begin{pmatrix} \sum_{j=1}^{q} \beta_{0j} GOLD_{t-j} \\ \sum_{j=1}^{q} \beta_{1j} BTC_{t-j} \end{pmatrix}$$

$$\begin{pmatrix} Q(\tau)(BTC_t|(BTC, SPX)_{t-1} \\ Q(\tau)(SPX_t|(BTC, SPX)_{t-1} \end{pmatrix} = \begin{pmatrix} \alpha_2(\tau) \\ \alpha_3(\tau) \end{pmatrix} + \begin{pmatrix} \sum_{j=1}^{p} \gamma_{2j} BTC_{t-j} \\ \sum_{j=1}^{p} \gamma_{3j} SPX_{t-j} \end{pmatrix} + \begin{pmatrix} \sum_{j=1}^{q} \beta_{2j} SPX_{t-j} \\ \sum_{j=1}^{q} \beta_{3j} BTC_{t-j} \end{pmatrix}$$

$$\begin{pmatrix} Q(\tau)(BTC_t|(BTC, GREEN)_{t-1} \\ Q(\tau)(GREEN_t|(BTC, GREEN)_{t-1} \end{pmatrix} = \begin{pmatrix} \alpha_4(\tau) \\ \alpha_5(\tau) \end{pmatrix} + \begin{pmatrix} \sum_{j=1}^{p} \gamma_{4j} BTC_{t-j} \\ \sum_{j=1}^{p} \gamma_{5j} GREEN_{t-j} \end{pmatrix} + \begin{pmatrix} \sum_{j=1}^{q} \beta_{4j} GREEN_{t-j} \\ \sum_{j=1}^{q} \beta_{5j} BTC_{t-j} \end{pmatrix}$$

$$\begin{pmatrix} Q(\tau)(GOLD_t|(GOLD, GREEN)_{t-1} \\ Q(\tau)(GREEN|(GOLD, GREEN)_{t-1} \end{pmatrix} = \begin{pmatrix} \alpha_8(\tau) \\ \alpha_9(\tau) \end{pmatrix} + \begin{pmatrix} \sum_{j=1}^{p} \gamma_{8j} GOLD_{t-j} \\ \sum_{j=1}^{p} \gamma_{9j} GREEN_{t-j} \end{pmatrix} + \begin{pmatrix} \sum_{j=1}^{q} \beta_{8j} GREEN_{t-j} \\ \sum_{j=1}^{q} \beta_{9j} GOLD_{t-j} \end{pmatrix}$$

$$\begin{pmatrix} Q(\tau)(GOLD_t|(GOLD, SPX)_{t-1} \\ Q(\tau)(SPX_t|(GOLD, SPX)_{t-1} \end{pmatrix} = \begin{pmatrix} \alpha_6(\tau) \\ \alpha_7(\tau) \end{pmatrix} + \begin{pmatrix} \sum_{j=1}^{p} \gamma_{6j} GOLD_{t-j} \\ \sum_{j=1}^{p} \gamma_{7j} SPX_{t-j} \end{pmatrix} + \begin{pmatrix} \sum_{j=1}^{q} \beta_{6j} SPX_{t-j} \\ \sum_{j=1}^{q} \beta_{7j} GOLD_{t-j} \end{pmatrix}$$

$$\begin{pmatrix} Q(\tau)(GREEN_t|(GREEN, SPX)_{t-1} \\ Q(\tau)(SPX_t|(GREEN, SPX)_{t-1} \end{pmatrix} = \begin{pmatrix} \alpha_{10}(\tau) \\ \alpha_{11}(\tau) \end{pmatrix} + \begin{pmatrix} \sum_{j=1}^{p} \gamma_{10j} GREEN_{t-j} \\ \sum_{j=1}^{p} \gamma_{11j} SPX_{t-j} \end{pmatrix} + \begin{pmatrix} \sum_{j=1}^{q} \beta_{10j} SPX_{t-j} \\ \sum_{j=1}^{q} \beta_{11j} GREEN_{t-j} \end{pmatrix}$$

Where BTC_t is Bitcoin, $GOLD_t$ is Gold and GREEN is Green Bond, which $(BTC, GOLD, SP500)_{t-1}$ is the past value of BTC_t, and $GREEN_t$ Where $\beta_{0q}(\tau)$, $\beta_{1q}(\tau)$, $\beta_{2q}(\tau)$, $\beta_{3q}(\tau)$, $\beta_{4q}(\tau)$, $\beta_{5q}(\tau)$, $\beta_{6q}(\tau)$, $\beta_{7q}(\tau)$, $\beta_{8q}(\tau)$, $\beta_{9q}(\tau)$, $\beta_{10q}(\tau)$ and $\beta_{11q}(\tau)$ It is a parameter value that indicates causality, which depends on the quantile-dependent sign, significance level, and magnitude in the conditional quantile $\tau \in (0, 1)$

The flexibility property of the quantile model makes it suitable for explaining the harmful responses of dependent variables that occur during periods of abnormally high or low levels of economic activity or Bitcoin prices. Two hypotheses that need to be tested are: $H_0: \beta_1(\tau) = \ldots = \beta_q(\tau) = 0$ for all $\tau \in (0, 1)$ against $H_A: \beta_j(\tau) \neq 0$ Where $j = 1, \ldots, q$

$H_0: \delta_1(\tau) = \ldots = \delta_q(\tau) = 0$ for all $\tau \in (0, 1)$ against $H_A: \delta_j(\tau) \neq 0$ Where $j = 1, \ldots, q$

According to Chuang et al. (2009), the conditional distribution will be estimated using a grid of 91 quantiles. Therefore, the two null hypotheses refer to testing on all 91 equally spaced quantiles only, and not testing on

4. Result

4.1 Results of the study on Quantile Vector autoregression

From Table 4.1.1, when considering the table, Gold has a positive relationship with Bitcoin, especially during market downturns (quantiles 0.1-0.3). For example, at the 1st quantile, a 1-unit increase in Bitcoin's growth rate results in a 0.3637-unit increase in gold's growth rate. This may indicate that investor's view both gold and Bitcoin as safe-haven assets during market downturns. The S&P 500 index has a significant positive relationship with Bitcoin across all quantiles, indicating a similar movement between the US stock market and Bitcoin. During stable market conditions (quantiles 0.4-0.6), the relationship between Bitcoin, gold, and the S&P 500 index remains positive but decreases in magnitude compared to market downturns. In bullish markets (quantiles 0.7-0.9), the relationship with the S&P 500 index remains positive but decreases in magnitude as the quantile increases. This suggests that during market downturns, investors turn to the stock market, while during stable and bullish market conditions, they turn to Bitcoin. This aligns with research by Symitsi and Chalvatzis (2019), which found that Bitcoin's relationship with the stock market varies across different periods, and Bitcoin may be useful for portfolio diversification at certain times. Green bonds have a significant positive relationship with Bitcoin, especially from quantiles 0.6-0.9.

Table 4.1.1 Coefficients of Independent Variables at Different Quantile Levels of Bitcoin (dlnBTC)

Quantile	Downtrend			Sideway Trend			Uptrend		
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
constant	-0.1112 *** (0.0096)	-0.0542 *** (0.0064)	-0.0305 *** (0.0053)	-0.0103 ** (0.0034)	0.0056 (0.0042)	0.0266 *** (0.0041)	0.0480 *** (0.0062)	0.0821 *** (0.0066)	0.1394 *** (0.0112)
dlnGOLD	0.3637 (0.6321)	0.5488 (0.4120)	0.3778 (0.3200)	0.2193 (0.2902)	0.1441 (0.2492)	0.1424 (0.2448)	-0.0954 (0.2927)	-0.0260 (0.3557)	0.6929 (0.7150)
dlnSPX	0.8425 * (0.5007)	0.7702 ** (0.3493)	0.7906 *** (0.2778)	0.7527 *** (0.2422)	0.6352 ** (0.2616)	0.6692 ** (0.3043)	0.3780 (0.2889)	0.2221 (0.3731)	0.4536 (0.6594)
dlnGREEN	0.3007 (1.6327)	0.3192 (0.6604)	0.3454 (0.5046)	0.4320 (0.4664)	0.0862 (0.5779)	0.2953 (0.5790)	0.5399 (0.6711)	1.0788 (1.2611)	0.6481 (1.5832)

Table 4.1.2 Coefficients of Independent Variables at Different Quantile Levels of Gold (dlnGOLD)

Quantile	Downtrend			Sideway Trend			Uptrend		
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
constant	-0.0227 *** (0.0019)	-0.0126 *** (0.0012)	-0.0069 *** (0.0008)	-0.0021 ** (0.0010)	0.0016 * (0.0008)	0.0053 *** (0.0007)	0.0092 *** (0.0010)	0.0147 *** (0.0011)	0.0241 *** (0.0017)
dlnBTC	-0.0047 (0.0150)	0.0129 (0.0120)	0.0133 (0.0100)	0.0107 (0.0088)	0.0093 (0.0089)	0.0092 (0.0061)	0.0064 (0.0094)	0.0022 (0.0091)	0.0179 (0.0177)
dlnSPX	-0.0588 (0.1583)	-0.1090 (0.1136)	-0.0595 (0.0637)	-0.0756 (0.0669)	-0.0899 ** (0.0420)	-0.1121 ** (0.0516)	-0.0914 (0.0688)	-0.0884 (0.0634)	-0.0961 (0.0739)
dlnGREEN	0.8340 *** (0.2451)	0.7694 *** (0.1280)	0.7765 *** (0.1196)	0.8721 *** (0.1349)	0.9397 *** (0.1060)	0.8775 *** (0.1150)	0.9001 *** (0.1181)	0.8995 *** (0.1247)	1.1022 *** (0.1904)

Table 4.1.3 Coefficients of Independent Variables at Different Quantile Levels of S&P500 Index (dlnSPX)

Quantile	Downtrend			Sideway Trend			Uptrend		
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
constant	-0.0210 *** (0.0026)	-0.0101 *** (0.0015)	-0.0038 *** (0.0010)	-0.0004 (0.0008)	0.0034 *** (0.0009)	0.0073 *** (0.0008)	0.0116 *** (0.0009)	0.0153 *** (0.0008)	0.0234 *** (0.0017)
dlnBTC	0.0340 ** (0.0148)	0.0279 *** (0.0102)	0.0133 * (0.0059)	0.0118 * (0.0047)	0.0119 (0.0060)	0.0083 (0.0093)	0.0022 (0.0079)	0.0088 (0.0090)	0.0029 (0.0106)
dlnGOLD	-0.2802 (0.1715)	-0.1478 * (0.0854)	-0.1103 ** (0.0508)	-0.1140 *** (0.0410)	-0.1062 ** (0.0531)	-0.0718 (0.0551)	-0.0561 (0.0710)	-0.0478 (0.0685)	-0.0188 (0.0840)
dlnGREEN	0.9595 *** (0.3582)	0.6378 *** (0.1811)	0.7584 *** (0.1365)	0.7269 *** (0.1165)	0.6762 *** (0.0902)	0.6126 *** (0.0921)	0.6208 *** (0.1137)	0.5853 *** (0.1400)	0.5598 *** (0.2134)

Table 4.1.4 Coefficients of Independent Variables at Different Quantile Levels of Green Bond (dlnGREEN)

Quantile	Downtrend			Sideway Trend			Uptrend		
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Intercept	-0.0090 *** (0.0010)	-0.0059 *** (0.0004)	-0.0041 *** (0.0004)	-0.0022 *** (0.0004)	-0.0007 * (0.0004)	0.0011 *** (0.0004)	0.0028 *** (0.0004)	0.0052 *** (0.0005)	0.0080 *** (0.0006)
dlnBTC	-0.0013 (0.0063)	-0.0006 (0.0027)	0.0014 (0.0026)	0.0048 (0.0031)	0.0041 (0.0030)	0.0027 (0.0035)	0.0011 (0.0032)	0.0035 (0.0034)	0.0055 (0.0048)
dlnGOLD	0.1960 *** (0.0488)	0.1587 *** (0.0197)	0.1572 *** (0.0180)	0.1675 *** (0.0187)	0.1734 *** (0.0162)	0.1674 *** (0.0238)	0.1647 *** (0.0284)	0.1529 *** (0.0209)	0.1307 *** (0.0294)
dlnSPX	0.1152 *** (0.0496)	0.1017 *** (0.0229)	0.0827 *** (0.0206)	0.0776 *** (0.0164)	0.0891 (0.0198)	0.0795 *** (0.0212)	0.0826 *** (0.0209)	0.0653 ** (0.0287)	0.0715 ** (0.0304)

Note: The asterisks (, **, **) indicate statistical significance at the 10%, 5%, and 1% levels, respectively. Values in parentheses represent standard errors.

Table 4.2 Results of causality tests between various financial assets during different market trend

Quantile	Downtrend			Sideway Trend			Uptrend		
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
dlnGOLD ⇨dlnBTC	0.8844	0.5342	0.4457	0.6570	0.3834	0.2957	0.6920	0.9133	0.8734
dlnBTC ⇨dlnGOLD	0.6810	0.0861	0.0020 **	0.0027 **	0.0226 *	0.1182	0.2419	0.3320	0.8806
dlnSPX ⇨dlnBTC	0.5946	0.0443 *	0.0393 *	0.0601	0.0441 *	0.0424 *	0.2611	0.4276	0.4497
dlnBTC ⇨dlnSPX	0.2339	0.0622	0.0000 ***	0.0803	0.3522	0.1339	0.2162	0.4869	0.2842
dlnGREEN ⇨dlnBTC	0.1948	0.1002	0.0278 *	0.0998	0.0737	0.2342	0.5899	0.5668	0.0428 *
dlnBTC ⇨dlnGREEN	0.8502	0.5226	0.0053 **	0.1403	0.2413	0.4019	0.6979	0.5453	0.7124
dlnSPX ⇨dlnGOLD	0.2824	0.2105	0.9537	0.6875	0.9623	0.6285	0.8675	0.5049	0.0990
dlnGOLD ⇨dlnSPX	0.4966	0.0541	0.0592	0.1386	0.6093	0.7382	0.4729	0.3901	0.4095
dlnGREEN ⇨dlnGOLD	0.0782	0.0000 ***	0.0000 ***	0.0000 ***	0.0000 ***	0.0000 ***	0.0000 ***	0.0160 *	0.0202 *
dlnGOLD ⇨dlnGREEN	0.2515	0.1576	0.0309 *	0.1194	0.0944	0.1196	0.1671	0.5349	0.9106
dlnGREEN ⇨dlnSPX	0.0096 **	0.0000 ***	0.0000 ***	0.0000 ***	0.0004 ***	0.0011 **	0.0460 *	0.2190	0.0874
dlnSPX ⇨dlnGREEN	0.0463 *	0.3400	0.9745	0.6025	0.2020	0.4616	0.5783	0.8223	0.2068

Note : The asterisks (, **, **) indicate statistical significance at the 10%, 5%, and 1% levels, respectively

From Table 4.1.2, Bouri et al. (2018) studied the relationship and spillover effects between Bitcoin and other assets during bull and bear markets. They found that the relationship between Bitcoin and gold changes over time and market conditions, not remaining constant. This aligns with the above study, which found that during bear markets (quantiles 0.2-0.3), there was a slight positive relationship between gold and Bitcoin, except in the 1st quantile where there was a negative relationship. During stable and bull markets (quantiles 0.4-0.9), the relationship remained positive but tended to decrease. The relationship between gold and the S&P500 index had a negative impact across all quantiles, consistent with the concept that gold is often used as a safe-haven asset during stock market volatility (Shahzad et al., 2019). Green bonds had a significant positive impact on gold across all quantiles, with the relationship tending to strengthen as quantiles increased. For example, when the gold growth rate increased by 1 unit, it resulted in an increase in the green bond growth rate of 0.7694 units at the 0.2 quantiles (downward trend), 0.9397 units at the 0.5 quantiles (stable trend), and 1.1022 at the 0.9 quantiles (upward trend). This result may reflect the growing trend of environmentally sustainable investments, which aligns with Reboredo's (2018) study that found a connection between gold and clean energy investments in the same direction.

From Table 4.1.3, The relationship between Bitcoin and the S&P500 index shows a positive correlation across all quantiles, with the relationship tending to decrease as quantiles increase, especially during bull markets. This finding aligns with Bouri et al.'s (2018) research, which found that Bitcoin has a positive relationship with the stock market, although this relationship may change depending on market conditions. Regarding the relationship with gold, a

negative correlation was found across all quantiles, with the negative relationship tending to weaken as quantiles increase. For example, if the S&P500 index growth rate increases by 1 unit, it will result in a decrease in the gold growth rate by 0.2802 units at the 0.2 quantiles, 0.1062 at the 0.5 quantiles, and 0.0478 units at the 0.8 quantiles. As for the relationship with green bonds, a significant positive correlation was found across all quantiles, with the relationship tending to be strongest during bear markets (0.1 quantiles). This result may reflect the growing trend towards sustainable investments, which aligns with Reboredo's (2018) study that found a connection between the stock market and clean energy investments.

From Table 4.1.4, it can be observed that green bonds and Bitcoin have a negative relationship in lower quantiles (0.1-0.2) and a positive relationship in higher quantiles (0.3-0.9). The relationship tends to increase from lower to higher quantiles. The relationship between green bonds and gold shows a clear positive correlation across all quantiles, with relatively high stability in all market conditions. This indicates that green bonds may possess safe-haven asset characteristics like gold. This result aligns with the study by Baur and Lucey (2010), which found that safe-haven assets often have positive correlations with each other. The relationship between green bonds and the S&P 500 index also shows a positive correlation across all quantiles, with the relationship remaining stable as well. This reflects that green bonds may receive increased attention during periods of stock market volatility. This finding may be consistent with research by Broadstock and Cheng (2019), which found that investments in green assets tend to increase during periods of general market uncertainty.

4.2 Results of the Study on Quantile Granger Causality

From Table 4.2 Dyhrberg's (2016) research examined Bitcoin's properties as a financial instrument, comparing it to gold. The study found that Bitcoin shares characteristics with gold as a financial asset and can serve as a hedging tool for stocks in the FTSE market. Bitcoin exhibited less volatility than commonly perceived and showed potential as an effective risk management tool. The results indicated that Bitcoin's financial properties lie between those of gold and the US dollar, possessing commodity-like characteristics. This aligns with the findings, which showed that during bear markets, gold has a stronger influence on Bitcoin than vice versa, with this relationship weakening during stable and bull markets. Thus, it can be concluded that gold and Bitcoin share similar safe-haven asset properties during periods of market volatility.

Corbet et al. (2018) investigated the relationship between digital currencies and traditional financial assets, comparing Bitcoin and other cryptocurrencies with various assets, including the S&P500 index. The study found a weak long-term relationship between Bitcoin and the S&P500, suggesting Bitcoin's potential utility in portfolio diversification. Although the overall relationship was weak, it tended to strengthen over time, particularly during periods of high market volatility. The relationship between Bitcoin and the S&P500 varied across different periods, potentially strengthening during market turbulence. Bitcoin demonstrated potential as a hedging instrument for US stock market investments in certain periods, but not consistently across all scenarios. These findings indicate that while Bitcoin and the S&P500 generally have a weak relationship, this relationship fluctuates with time and market conditions. This aligns with the Quantile Granger Causality analysis conducted in the study, which revealed varying relationships across different quantiles and market states. The table shows that during severe bear markets (0.1 quantiles), the S&P500 significantly influences Bitcoin, but not vice versa. In stable markets (0.5quantiles), the S&P500

maintains a significant influence on Bitcoin, while Bitcoin also influences the S&P500, albeit to a lesser extent (higher p-value). These results reflect the overall relationship between Bitcoin and the stock market, with the S&P500 exerting a stronger influence on Bitcoin, especially during bear and stable market conditions.

The table also shows the relationship between green bonds and the S&P500, with p-values of 0.0000 across all quantiles (0.1, 0.5, and 0.9), indicating that green bonds significantly influence the S&P500 in all market conditions. Regarding the relationship between green bonds and gold, p-values are 0.0460, 0.3280, and 0.0020 for quantiles 0.1, 0.5, and 0.9, respectively, suggesting significant relationships during bear and bull markets, but not during stable markets. For green bonds and Bitcoin, p-values are 0.7340, 0.0180, and 0.4060 for quantiles 0.1, 0.5, and 0.9, respectively, indicating a significant relationship only during stable markets. These relationships demonstrate that green bonds consistently influence the S&P500 across all market conditions, while their relationships with gold and Bitcoin vary across quantiles, reflecting the complexity of these asset interactions in different market states.

The relationship between gold and the S&P500 index varies across quantiles. During bear markets, gold has a stronger influence on the S&P500, but this relationship changes during stable and bull markets. This aligns with Baur and Lucey's (2010) research, which found that gold plays a safe-haven role during periods of market volatility.

5. Conclusion

This study is significant as Bitcoin has garnered increased attention as an investment asset with characteristics like gold, despite its high volatility. Understanding the relationship between Bitcoin and other assets will aid investors in portfolio allocation decisions and risk management, especially during periods of high market volatility. This study focuses on examining the asymmetric relationships between Bitcoin and other financial assets. Baur's (2018) findings indicate that Bitcoin is more volatile than typical assets and cannot serve as a safe-haven asset, while gold plays a safe-haven role during market volatility. Broadstock and Cheng (2019) found that investments in green assets tend to increase during periods of high stock market volatility. Corbet et al. (2018) observed a weak long-term relationship between Bitcoin and the S&P 500 index, though this relationship tends to strengthen over time. However, there is limited empirical work on the relationships between Bitcoin, gold, the S&P 500 index, and green bonds. Therefore, this research focuses on studying the asymmetric relationships and causality between Bitcoin and other financial assets.

The first part of the study, using Quantile Vector Autoregression, found that Bitcoin and gold have a positive relationship, especially during bear markets, suggesting investors view both as safe-haven assets during downturns. However, this relationship tends to weaken in bull markets. Bitcoin and the S&P 500 index show a significant positive relationship across all quantiles, indicating co-movement between the US stock market and Bitcoin. This relationship tends to weaken at higher quantiles, suggesting investors may diversify more into other assets during bull markets. Bitcoin and green bonds exhibit a significant positive relationship, particularly at higher quantiles, indicating that Bitcoin investors may place more importance on sustainable investments in low-risk market conditions. Gold and the S&P 500 index show a negative relationship across all quantiles, consistent with the notion that gold is often used as a safe-haven asset during stock market volatility. Gold and green bonds demonstrate a significant positive impact across all quantiles, with the relationship strengthening at higher quantiles, reflecting the growing trend of environmentally sustainable investments.

The S&P 500 index and green bonds show a significant positive relationship across all quantiles, with the strongest relationship during bear markets, indicating an increasing trend toward sustainable investments.

The Quantile Granger Causality analysis revealed that during bear markets, gold significantly influences Bitcoin, suggesting investors may view gold as a primary safe-haven asset, potentially affecting Bitcoin investment decisions. This relationship weakens during stable and bull markets. The S&P 500 index significantly influences Bitcoin during severe bear markets, while Bitcoin does not influence the S&P 500 index. In stable markets, the S&P 500 index maintains a significant influence on Bitcoin, while Bitcoin also influences the S&P 500 index to a lesser extent. These findings align with Corbet et al. (2018), suggesting Bitcoin may be useful for portfolio diversification, but the stock market's influence on Bitcoin may increase during bear markets. Green bonds show a significant relationship with Bitcoin only during stable markets. The relationship between gold and the S&P 500 index varies across quantiles, with gold having a stronger influence on the S&P 500 during bear markets, consistent with Baur and Lucey's (2010) findings that gold is often used as a safe-haven asset during market volatility. Green bonds significantly relate to gold during bear and bull markets but not during stable markets. Green bonds significantly influence the S&P 500 index across all market conditions, indicating that sustainable investments may influence the overall US stock market.

Policy Recommendations

1. For Investors: The study indicates that Bitcoin's relationship with other assets varies across market conditions. Therefore, diversifying portfolios to include multiple asset types, including an appropriate proportion of Bitcoin, can help mitigate risk. Gold continues to serve as a safe-haven asset during bear markets, particularly when compared to Bitcoin. Thus, investors seeking to reduce risk during market volatility should consider gold investments. Green bonds demonstrate positive correlations with both the stock market and gold, especially during bear markets, reflecting growth opportunities and effective risk management. Consequently, investors seeking sustainable investment opportunities should consider green bonds. Given the complex and dynamic relationships between assets across market conditions, investors should diligently monitor information and analyze environmental factors before making investment decisions.
2. For Government: Authorities should promote public understanding of digital assets like Bitcoin to facilitate informed investment decisions. Appropriate regulation of the digital asset market is necessary to mitigate risks and instill investor confidence. The study's findings underscore the importance of green bonds; therefore, the government should encourage and support investments in environmentally friendly projects to attract capital and drive the green economy.
3. For Financial Institutions: There is a need to develop products and services related to digital assets to meet growing investor demand. Financial institutions should create digital asset-related offerings, such as cryptocurrency mutual funds. They should also provide investment advice that considers individual risk

tolerances and objectives, particularly for investments in highly volatile assets.

4. For Researchers: Further studies should be conducted on factors influencing relationships between various assets to enhance understanding of capital market dynamics. Researchers should develop models and tools for analyzing asset relationships and assessing risks.

Research Limitations

1. This study focuses on the relationship between Bitcoin and specific financial assets, which may not encompass other financial assets that could have significant relationships with Bitcoin.
2. Given Bitcoin's relatively recent emergence, the timeframe of analyzed data may be limited, potentially failing to reflect long-term relationships or complete economic cycles.
3. The analysis may not control for all external factors that could influence asset relationships, such as monetary policy changes, global economic events, or regulatory shifts pertaining to cryptocurrencies.

Suggestions for Future Research

1. Expand the scope of assets studied: Examine relationships between Bitcoin and other digital currencies such as Ethereum and Ripple and analyze correlations with alternative asset classes like real estate and commodities.
2. Investigate the impact of external factors: Analyze the effects of monetary policy and macroeconomic factors on the relationship between Bitcoin and other assets. Study the influence of regulatory changes concerning cryptocurrencies in various countries.
3. Develop forecasting models: Construct models utilizing asymmetric relationships to predict Bitcoin prices or volatility and test the model's efficacy in real-world applications.

References

[1] Ang, A., & Chen, J. (2002). Asymmetric correlations of equity portfolios. Journal of Financial Economics, 63(3), 443-494.
[2] Baur, D. G., & Lucey, B. M. (2010). Is gold a hedge or a safe haven? An analysis of stocks, bonds and gold. Financial Review, 45(2), 217-229.
[3] Baur, D. G., & McDermott, T. K. (2010). Is gold a safe haven? International evidence. Journal of Banking & Finance, 34(8), 1886-1898.
[4] Baur, D. G., Dimpfl, T., & Kuck, K. (2018). Bitcoin, gold and the US dollar – A replication and extension. Finance Research Letters, 25, 103-110.
[5] Bouri, E., Gupta, R., Tiwari, A. K., & Roubaud, D. (2017). Does Bitcoin hedge global uncertainty? Evidence from wavelet-based quantile-in-quantile regressions. Finance Research Letters, 23, 87-95.
[6] Broadstock, D. C., & Cheng, L. T. (2019). Time-varying relation between black and green bond price benchmarks: Macroeconomic determinants for the first decade. Finance Research Letters, 29, 17-22.
[7] Cecchetti, S. G., & Li, H. (2008). Measuring the impact of asset price booms using quantile vector autoregressions. Brandeis University Department of Economics and International Business School Working Paper.
[8] Chuang, C. C., Kuan, C. M., & Lin, H. Y. (2009). Causality in quantiles and dynamic stock return–volume relations. Journal of Banking & Finance, 33(7), 1351-1360.

[9] Corbet, S., Meegan, A., Larkin, C., Lucey, B., & Yarovaya, L. (2018). Exploring the dynamic relationships between cryptocurrencies and other financial assets. Economics Letters, 165, 28-34.

[10] Diebold, F. X., & Yilmaz, K. (2012). Better to give than to receive: Predictive directional measurement of volatility spillovers. International Journal of Forecasting, 28(1), 57-66.

[11] Dyhrberg, A. H. (2016). Bitcoin, gold and the dollar – A GARCH volatility analysis. Finance Research Letters, 16, 85-92.

[12] Flammer, C. (2021). Corporate green bonds. Journal of Financial Economics, 142(2), 499-516.

[13] Guesmi, K., Saadi, S., Abid, I., & Ftiti, Z. (2019). Portfolio diversification with virtual currency: Evidence from bitcoin. International Review of Financial Analysis, 63, 431-437.

[14] Longin, F., & Solnik, B. (2001). Extreme correlation of international equity markets. The Journal of Finance, 56(2), 649-676.

[15] Rapach, D. E., Strauss, J. K., & Zhou, G. (2013). International stock return predictability: What is the role of the United States? The Journal of Finance, 68(4), 1633-1662.

[16] Reboredo, J. C. (2018). Green bond and financial markets: Co-movement, diversification and price spillover effects. Energy Economics, 74, 38-50.

[17] Shahzad, S. J. H., Bouri, E., Roubaud, D., Kristoufek, L., & Lucey, B. (2019). Is Bitcoin a better safe-haven investment than gold and commodities? International Review of Financial Analysis, 63, 322-330.

[18] Symitsi, E., & Chalvatzis, K. J. (2019). The economic value of Bitcoin: A portfolio analysis of currencies, gold, oil and stocks. Research in International Business and Finance, 48, 97-110.

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Humanities and social sciences

Environmental Impact and Challenges of Cardless Banking

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Abstract
This study explores the awareness, usage, convenience, accessibility, security, enhancement and challenges associated with cardless banking services to withdraw cash from ATM. Cardless banking enables financial transactions and account management without the need for a physical bank card, leveraging technologies such as mobile banking apps, online banking platforms, biometric authentication, QR codes, NFC, and one-time passwords (OTPs) and to withdraw cash from ATM. With cardless ATMs, one can access the account and make cash withdrawals without a card. Rather, they depend on account verification through text message or a mobile banking app.To gather insights, a questionnaire was developed, addressing demographic information, awareness and usage of cardless banking, perceptions of convenience and accessibility, security and trust concerns, and challenges faced by users. The survey aims to minimize reliance on physical cards, to have better access to banking services and to contribute to environmental sustainability. The findings from this survey will provide a comprehensive understanding of user experiences with cardless banking, highlighting both the benefits and areas needing enhancements and give recommendations. This information can guide financial institutions.

Keywords: Cardless, Biometric authentication, QR codes, NFC

Introduction:
A major change in the way financial transactions are carried out is represented by cardless banking, which substitutes increasingly digital and mobile-based solutions for traditional physical cards. Many environmental advantages result from this shift, chief among them being the decrease of paper receipts and plastic trash. (Nambiar, B.K., Bolar, K. ,2024)[1] Plastic card manufacturing and disposal add to resource depletion and environmental damage. Cardless banking contributes to international initiatives for environmental preservation and sustainability by reducing the need for these tangible goods. (I.U., Hameed, Z., Khan, S.U. et al. 2024)[2] But making the switch to a cardless banking system is not without its difficulties. Customers and financial institutions have to deal with challenges such managing the shift for customers used to traditional banking methods, addressing technological impediments, and guaranteeing strong cybersecurity. To guarantee that all users may profit from these developments without sacrificing security or accessibility, there is also a need for mass education and adaption to new technology.

For cardless banking to be successfully adopted, a number of issues need to be resolved. First and foremost, cybersecurity issues are critical since digital banking platforms are increasingly being targeted by cyberattacks, requiring strong security protocols to ward off threats and guarantee data privacy. (Iyabode, A. M., et al) [3] Second, limitations related to technology, like restricted access to the internet and cellphones, along with the requirement for teaching digital literacy, make widespread utilization difficult. Further difficulties come with infrastructure and implementation, which call for large sums of money to be invested in system upgrades and smooth interface with current banking procedures. Additionally, user adaption and trust are

important, since some customers might not want to switch from traditional ways and might have doubts about the security of cardless solutions.

Financial institutions need to establish their credibility by proving how convenient and safe these services are. Finally, banks must manage intricate rules and guarantee continuous adherence to developing standards concerning digital transactions and cybersecurity due to regulatory and compliance difficulties. Financial institutions must successfully handle these issues in order to offer safe, practical, and sustainable banking solutions, eventually advancing both technology and the environment more broadly.

1. **Cybersecurity Concerns:**
   - **Threats and Vulnerabilities:** The shift of banking to digital platforms exposes it to cyberattacks. It is critical to guarantee the security of digital transactions, online platforms, and mobile apps.
   - **Data Privacy:** Preserving client information against security lapses and unapproved access is a vital worry. Financial institutions need to put strong security and encryption in place.
2. **Technological Barriers:**
   - **Access to Technology:** It may be difficult for certain clients to use cardless banking services since they do not have access to cellphones or the internet.
   - **Digital Literacy:** Customers need to be taught how to use digital banking tools safely and effectively, especially older folks and those who are less tech-savvy.
3. **Infrastructure and Implementation:**
   - **Upgrading Systems:** It can be expensive and time-consuming for financial institutions to update their infrastructure in order to facilitate cardless transactions.
   - **Integration with Existing Systems:** It can be difficult to prove that new cardless solutions operate well with current banking procedures and systems.
4. **User Adaptation and Trust:**
   - **Resistance to Change:** Some customers could find it difficult to give up on conventional banking practices, and they might have doubts about the dependability and security of cardless solutions.
   - **Building Trust:** Financial institutions need to prove customers the security and ease of cardless banking in order to earn and keep their trust.
5. **Regulatory and Compliance Issues:**
   - **Regulatory Requirements:** Banks have to operate through difficult regulatory environments to guarantee that their cardless banking solutions adhere to financial regulations and norms.
   - **Ensuring Compliance:** Maintaining compliance with ever-changing cybersecurity and digital transaction legislation is crucial to avoiding legal problems and fines. (Bhosale,S. T et al)[4]

Key Features of Cardless Banking

1. **Mobile Banking Apps**: Customers can use their smartphones to access their accounts, transfer funds, pay bills, and more. (Kosim, K. P.et al)[5]
2. **Online Banking**: Web-based platforms allow users to manage their finances from their computers.
3. **Biometric Authentication**: Technologies like fingerprint and facial recognition can be used to authenticate transactions.
4. **QR Codes and NFC**: Transactions can be initiated and completed using

QR codes or near-field communication (NFC) technology.
5. **One-time Passwords (OTPs)**: OTPs sent to the user's mobile phone can be used to authenticate transactions.

Advantages

1. **Convenience**: Users can access their accounts anytime and anywhere without needing a physical card.
2. **Security**: Advanced authentication methods can enhance security and reduce the risk of card-related fraud.
3. **Cost Savings**: Reduces the need for physical card production and distribution.
4. **Accessibility**: Enables banking access for people who may not have easy access to traditional banking infrastructure.

Research Gap

Despite the increasing adoption of cardless ATMs that offer convenient and secure access to banking services through mobile authentication, there remains a lack of comprehensive studies examining the impact of these technologies on user behavior, security perceptions, and overall satisfaction compared to traditional card-based ATMs. Understanding these aspects is crucial for banks and policymakers to effectively tailor their strategies and regulations to meet evolving consumer preferences and ensure robust cybersecurity measures.

Challenges

1. **Digital Divide**: Not all customers may have access to smartphones or reliable internet connections.
2. **Security Concerns**: While cardless banking can enhance security, it also introduces new risks like phishing and hacking.
3. **Adoption Resistance**: Some customers may be hesitant to adopt new technologies and prefer traditional banking methods.

Objectives of Cardless Banking

- ✓ To minimize reliance on physical cards by enabling users to complete banking transactions anytime, anyplace, to withdraw cash from ATM without a card.
- ✓ To have better access to banking services, especially those who live in remote areas or have restricted access to traditional bank branches, promoting convenience and financial inclusion.
- ✓ To contribute to environmental sustainability by reducing the use of plastic cards and paper receipts, aligning with global efforts towards eco-friendly practices.

RESEARCH METHODOLOGY

Research Design

Descriptive research design was used in this study.

Sources of Data

- ✓ Primary Data: The primary data were collected based on the structured questionnaire.
- ✓ Secondary Data: The secondary data for the study have been collected from articles and websites.

Sampling Technique

The sampling techniques used for the study is simple random sampling. Collected data from the individuals who visit the ATM center in and around Coimbatore to withdraw cash using cardless option.

Sampling Size

The sample size was collected from 100 respondents.

Tools used for the study

1. Chi- square test
2. Correlation

Review of Literature

1. Lowenstein and Hafalir conducted a study in 2012 on "The Impact of Credit Cards on Spending." Credit card usage's effect on expenditure. The study concentrated on two consumer categories: those with debt and those without. Those with debt are referred to as revolvers, while those without debt are referred to as convenience users. The impact of using a credit card instead of cash to pay for lunch at a cafeteria was examined in this study involving employees of an insurance company. It was discovered that when a credit card was offered as a payment option, consumers switched from using cash to credit cards. Subsequent research revealed that credit cards do not lead to increased expenditure.

However, revolvers and convenience users are affected by credit card use differently in terms of expenditure. When forced to make purchases with a credit card, revolvers spend less, while convenience users behave differently.

2. Bansi Patel and Urvi Amin (2012), in their research paper "Plastic Money: A Roadway Towards Cashless Society," discussed that these days, in any transaction, plastic money becomes an essential component, making life easier and contributing to better development. It also makes it possible to control money laundering and make efficient use of the financial system, both of which are beneficial for tax legislation.

3. P. Manivannan (2013), in his research paper "Plastic Money: A Way for Cash Less Payment System," examined that credit card use, or "plastic money," was once considered a luxury but is now considered necessary. Only those with better incomes used electronic payments and plastic money. Customers living in rural areas might also utilize this option, in addition to those in metropolitan areas. But as banking and trading have grown, the salaried classes and those with fixed incomes have also begun to use plastic money and computerized payment methods, especially credit cards.

4. Nirmala. R. Sonu (2015): "Analysis of the use of Plastic Money" emphasized the advantage of fast transactions, which is a major factor in the modern population's preference for using plastic money rather than cash. The simplicity of transactions and the convenience of not having to carry cash are two major psychologically significant factors that lead people to use plastic money instead of actual cash, as the study has already demonstrated. The study's conclusions also underlined how easy and convenient it is to make payments or purchases using plastic money. Time savings and the seeming increased portability of plastic money appear to be contributing factors to a potential shift in the way money is used in the economy.

Analysis and Interpretation

Ho: There is no significant relationship between gender and security, usage, awareness and environmental sustainability.

Table 1: Comparison between gender and security, Usage, awareness and environmental sustainability

Variables	Value	Df	Asymptotic Significance
Security,	38.339[a]	3	.01
Usage	36.092[a]	3	.012
Awareness	86.321[a]	3	.011
Environmental Sustainability	46.706[a]	3	.024

From the above it is clear that the P value is less than the 5% level of satisfaction therefore the null hypothesis is rejected

Hence there is significant relationship between gender and security, usage, awareness and environmental sustainability.

Table :2 Correlation between Usage and Location

		Usage	Location
Usage	Pearson Correlation	1	.142
	Sig. (2-tailed)		.321
	N	100	51
Location	Pearson Correlation	.142	1
	Sig. (2-tailed)	.321	
	N	51	100

The Pearson's correlation is +1 (.142) indicates the positive correlation between usage and location and it shows variables are moving in same direction. This means that there is a slight tendency for the usage and location variables to increase together, but the relationship is not strong. They move in the same direction, but not in a strongly correlated manner.

Table:3 Correlation between Enhancements and Location

		Enhancements	Location
Enhancements	Pearson Correlation	1	.174
	Sig. (2-tailed)		.071
	N	100	100
Location	Pearson Correlation	.174	1
	Sig. (2-tailed)	.071	
	N	100	100

The Pearson's correlation is +1 (.174) indicates the positive correlation between enhancements and location and it shows variables are moving in same direction. This means that there is a slight tendency for enhancements and location to increase together, but the relationship is not strong. They move in the same direction, but the correlation is weak.

Recommendations and Conclusion:

- ✓ As an additional security measure, use geolocation data to confirm the user's location during transactions.
- ✓ Customers should be informed about the advantages and security measures of cardless banking so they can use the service with confidence.
- ✓ Provide emergency access tools that let users rapidly report unauthorized activity or temporarily disable cardless transactions.
- ✓ Provide round-the-clock customer support devoted to cardless banking queries and issues.
- ✓ Update and enhance security procedures and user interface on a regular basis in response to user input and new technological developments.

The study concludes that resource efficiency, a decrease in carbon footprint, and a reduction in plastic waste all ways greatly support environmental sustainability. The banking industry may lessen its environmental effect while offering consumers effective and convenient services by using sustainable practices and utilizing renewable energy.

Acknowledgement

I thank the Lord Almighty for the grateful blessings showered on me to complete this article.

I am truly indebted to Rev.Sr. Kulanthai Therese, M.Sc., M.Phil., M.Ed., PGDCA.,Ph.D.,,Secretary of Nirmala College for Women (Autonomous), Coimbatore, for her encouragement and support.

I express my gratitude to Rev.Sr. Dr. Mary Fabiola, M.SC., M.Phil., PGDCA, Ph.D., Principal of Nirmala College for Women (Autonomous), Coimbatore, for providing the

opportunity to participate in the conference. My heartfelt thanks and I feel extremely privileged and guidance of Rev. Sr. Dr.S. Emelda Mary, M.A., M.Phil., B.Ed., Ph.D., Vice-Principal of Nirmala College for Women (Autonomous), Coimbatore, for motivating to participate in the conference.
I am deeply indebted to Dr. R.Devi Prasanna., Assistant Professor, Mrs.K.Princy Hebshibha Assistant Professor, Nirmala College for Women and my family for their constant support and encouragement. I am grateful to my friends for providing worthwhile suggestions for the betterment of the article.

References:

[1] Nambiar, B.K., Bolar, K. Factors influencing customer preference of cardless technology over the card for cash withdrawals: an extended technology acceptance model. *J Financ Serv Mark* **28**, 58–73 (2023).
[2] I.U., Hameed, Z., Khan, S.U. *et al.* Green banking practices, bank reputation, and environmental awareness: evidence from Islamic banks in a developing economy. *Environ Dev Sustain* **26**, 16073–16093 (2024).
[3] Iyabode, A. M., Nureni, Y. N., Adebayo, A. F., & Olamide, O. A. (2015). Card-less electronic automated teller machine (EATM) with biometric authentication. *International Journal of Engineering Trends and Technology (IJETT)*, *30*(1), 511-516.
[4] Bhosale, S. T., & Sawant, B. S. (2012). Security in e-banking via cardless biometric ATMs. *International Journal of Advanced Technology & Engineering Research*, *2*(4), 457-462.
[5] Kosim, K. P., & Legowo, N. (2021). Factors affecting consumer intention on QR payment of mobile banking: A case study in Indonesia. *The Journal of Asian Finance, Economics and Business*, *8*(5), 391-401.
[6] Incekara-Hafalir, E., & Loewenstein, G. (2009). The impact of credit cards on spending: a field experiment. Available at SSRN 1378502.
[7] Patel, B., & Amin, U. (2012). Plastic Money: Road may Towards Cash Less Society. Paripex Indian journal of Research, 1(11).
[8] Manivannan, P. (2013). Plastic money a way for cash less payment System. Global Research Analysis, 2(I. 8).
[9] Dhanda, K., & Arora, U. (2017). Genesis of cashless society: A study on growing acceptability of plastic money. Genesis, 2(5).
[10] Infanta, A. V. A study on customer perception towards plastic money (with reference to Coimbatore city).
[11] Mahesha, V. Challenges and Opportunities of Plastic Money in Indian Economy-an Exploratory Study.

A Study on Overcoming Consumer's Skepticism towards Organic Product through Effective Sustainable Marketing

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Abstract
Organic products have gained popularity in recent years owing to their health and environmental benefits. However, consumer skepticism remains a significant barrier to widespread adoption. Chi-square Tests and Karl Pearson Coefficient Correlation techniques have been used. Chi –Square showed the result that there is no significant relationship, which leads to the conclusion that the obstacles of adopting organic products to overcome consumer skepticism about organic products are unrelated to respondents' age and correlation analysis gives a positive relationship between the reasons for utilizing organic goods with the tactics for overcoming consumer skepticism about organic products. The findings highlight number of issues that contribute to consumer skepticism, including high prices when compared to regular goods, a lack of knowledge about sustainable farming practices, label and certification confusion, the impact of similar flavor and quality on non-organic items, availability, and trust. In response to these findings, the study suggests several sustainable marketing solutions. Furthermore, the study identifies many sustainable marketing strategies that have the potential to reduce customer skepticism. These strategies include transparency and education, emphasizing quality and flavor, targeting the right customers, reducing packaging waste, and collaborating with sustainable businesses. This study aims to encourage changes toward more sustainable purchase behaviors by addressing the identified skeptical features and delivering successful sustainable marketing techniques. The outcomes of this study can help marketers promote organic food consumption and enhance customer support for sustainable agriculture approaches. The study's major goal is to use these strategies to increase consumer trust and confidence in purchasing organic products, resulting in greater adoption and support for sustainable agriculture practices in order to achieve a low-carbon society.
Keywords: Sustainable marketing, marketing strategies, organic practices, consumer doubts

1. Introduction

Consumers' distrust about organic products has become a key obstacle to sustainable consumption. Despite increasing knowledge of the environmental and health benefits of organic products, many customers remain skeptical due to perceived high costs, worries about authenticity, and a lack of clear comprehension of the benefits.[1]

Organic products are made using natural components and do not contain fertilizers or synthetic chemicals. To be considered organic, a product must have been produced in a way that respects the soil, conserves its nutrients, avoids the use of chemicals, and has been certified according to ecological criteria. By avoiding extended contact with chemical products, it protects not only the health of the customers, but also the health of the

farmers and workers engaged in its production [2]. Marketers may foster trust and a good view of organic foods by utilizing open communication, reliable certifications, and promoting the advantages of organic consumption. This research investigates several sustainable marketing strategies for reducing skepticism and increasing customer acceptance of organic products. [3] As a result, addressing consumer mistrust about organic products is critical to the economy's organic food sector growth. One key area of consumer doubt is the legitimacy of organic claims. Customers often question whether products labeled as organic genuinely meet the standards and regulations associated with organic production. This mistrust may be fueled by instances of misleading labeling or insufficient regulation enforcement.

2. Objectives

- To identify the key factors contributing to consumer skepticism towardsorganic products
- To analyze the challenges in sustainable marketing of organic products
- To identify the reason in consuming organic products.

2.1 Statement of the problem

The problem statement identifies a substantial market difficulty for organic products. This criticism originates from a variety of issues, including concerns about the truthfulness of organic claims, higher pricing, and a perceived lack of real benefits like health benefits and environmental benefits when compared to conventional products. These issues combined hinder market penetration of organic products, hence slowing the development of sustainable consumption behaviours. Another key aspect is the increased cost of organic food. Organic agricultural methods often include more labour-intensive processes, resulting in higher expenses. These variables work together to explain organic products' poor market penetration. When customers are unwilling to trust or invest in these items, the wider adoption of sustainable consumption practices suffers. This has an impact on the overall growth and sustainability of the organic product industry. To overcome these difficulties, the study will look at the precise causes for customer distrust. By learning about these concerns, businesses may modify their marketing efforts to better meet the requirements and expectations of their customers. This might include better labelling, more explicit communication about the benefits of organic food, and strategies for justifying the price premium.Addressing these concerns would enable to better match their marketing efforts with customer expectations, resulting in a more sustainable market environment. The research aims to uncover the root causes of consumer skepticism towards organic products and to develop marketing strategies that address these concerns.

2.2 Need for the study

Understanding and overcoming consumer concern about organic products is critical for promoting a sustainable future.Overcoming these issues is critical for promoting environmentally friendly practices and improving public health outcomes by encouraging the use of items free of synthetic pesticides and fertilizers.This research aims to contribute to create a more sustainable market environment in which organic products are recognized for their genuine benefits. By identifying and resolving the causes of consumer mistrust, the study hopes to enhance both environmental and economic sustainability. Effective sustainable marketing methods may play an important part in restoring consumer trust and transparency while also addressing the root cause of skepticism. The study's findings can assist policymakers and regulatory authorities in developing stronger standards and policies to foster the growth of the organic industry.

By expanding a comprehensive knowledge of consumer issues and developing methods to address them, this study may pave the way for a more sustainable and successful future for the organic product in the market, as well as the transition to a low-carbon society.

2.3 Scope of the s Scope of the study

This research focuses on overcoming customer distrust about organic products using sustainable marketing tactics. The key areas of inquiry are: Understanding consumer resistance towards organic products, including misinformation, distrust in certifications, and perceived high costs. Identifying effective ways to build customer confidence and promote organic products. This includes strategies such as increasing transparency in labeling and strengthening certification processes, consumer education through campaigns and workshops, addressing price perceptions, engaging in digital and social media platforms, fostering community relationships, highlighting health and environmental benefits with scientific evidence, improving product accessibility, and continuous innovation in sustainable practices. By exploring these factors, this study hopes to give practical knowledge and suggestions for organic product marketers and stakeholders looking to effectively overcome consumer uncertainty and drive broader adoption of sustainable.

2.4 Review of Literature

"The willingness to consume organic food" by Gabriel Adewunmi Eyinade and Abbyssinia Mushunje (2021),[4] seeks thisarticle investigates consumer inclination to eat organic food, as well as consumer knowledge and awareness of organic food, and consumer attitudes and preferences for organically grown foods. The results of this study show that the food industry has to promote more awareness about the health benefits of consuming organic foods. The gradual increase in organic food production may also be seen in the rapidly rising. Indian farmers experience with and perception of organicfarming", [5] despite a lack of official assistance in providing farmers with information andextension, the number of farmers turning to organic farming in India has surged in recent years. The purpose of this essay is to look into the perceived importance, benefits, and challenges of switching to organic farming. A total of 40 farmers, both organic and conventional, were interviewed. According to the findings, conventional farmers cited production and marketing difficulties as the key impediments to organic farming adoption, whereas the farmer's age and education were not considered an issue. Conversion was further hampered by a lack of information and institutional assistance. According to the research, the government's compensation programmed for yield loss during the conversion period, as well as a price premium may be effective.

'Exploring the Preferences of Consumers' Organic Products in Aspects of Sustainable Consumption: The Case of the Polish Consumer' [6]. The article aimed to examine Polish consumers' behavior in the organic product market and explore the relationship between their environmental awareness and willingness to purchase organic products. The authors suggested a link between consumer knowledge of sustainable consumption and the use of organic products. The study involved 1067 participants, using a unique survey questionnaire. Statistical analysis, including descriptive statistics, discriminant function analysis, and regression analysis, was conducted with the Statistical 13.1 PL program. The findings have implications for industry professionals and policymakers to encourage more sustainable eating habits. The authors recommend that food systems policy groups develop new campaigns to educate the public on the benefits of consuming organic foods.

2.5 Research Gap

The influence of digital marketing and social media on consumer attitudes regarding organic products has not been fully studied. Understanding how online platforms encourage or prevent organic product adoption might give valuable insights as they become increasingly influential in shaping customer opinions. If customers are provided with clear information and understanding about organic products, and labels are transparent, consumer distrust may be eliminated.

Research on overcoming consumer skepticism regarding organic products involves an in-depth research of skepticism as well as an examination of psychological obstacles and trust variables. All of the challenges, such as limited product availability, organic label bias, lack of information clarity, and perception of similar taste to non-organic alternatives, have been reported by customers, and barriers such as higher prices, fewer retail organic outlets, shorter shelf life, and lack of trust must be identified in order to fill the study's research gap.

2.6 Materials and Methods

a) Area of Study

The study has conducted in Coimbatore district, Tamil Nadu, India.

b) Sampling Techniques

The sample strategy utilized in this study is simple random sampling across different demographics.

Simple Random Sampling: A type of probability sampling where a subset of participants is chosen at random from a population.

c) Tools of Analysis

The SPSS package used for the study

Chi - square tests, Karl Pearson Coefficient of Correlation are used to analyses the data. Appropriate tables are used to present the results.

d) Source of data

Primary data: Well- structured questionnaire framed to capture consumer attitude and trust levels.

Secondary data: Articles related to organic products, Journals and information's were from websites such as Google Scholar, Google, Shodganga, and Research Gate.

3 Analysis and Interpretation

3.1 Chi- Square Test

Chi – square test is a data analysis on the basis of observations of a random set of variables. Usually, it is a comparison of two statistical data sets. This test was introduced by Karl Pearson in 1900 for categorical data analysis and distribution. [7]

H0: There is no significant relationship between respondent's ages and challenges in using organic product.

Table 1 Comparison between respondent's age and challenges in using organic product

Chi-Square Tests			
	Value	df	Asymptotic Significance(2-sided)
Pearson Chi-Square	23.293[a]	20	.275
Likelihood Ratio	24.708	20	.213
Linear-by-Linear Association	8.527	1	.003

Table 1 show that the Pearson Chi-Square value is 23.293 at the 5% level of significance. P value is greater than 0.05, hence the null hypothesis is accepted.

Findings from Table 1

There is no significant relationship, which leads to the conclusion that the obstacles of employing organic products to overcome consumer skepticism about organic products are unrelated t o respondents' ages.

Contingency Coefficient

The contingency coefficient is a coefficient of association that tells

whether two variables or data sets are independent or dependent of each other. It is also known as Pearson's Coefficient. [8]

Table 2 Contingency Coefficient relationship betweenage and challenges in using organic product

Symmetric Measures			
		Value	Approximate Significance
Nominal by Nominal	Phi	.763	.275
	Cramer's V	.382	.275
	Contingency Coefficient	**.607**	**.275**

Table 2 shows a Contingency Coefficient of 0.607, which is above 0.60 so it is indicating a strong relationship between challenges in utilizing organic products to overcome consumer skepticism and respondents' age*.
*Respondents age is selected randomly from customers using organic products probably between 30years to 60 years through structured questionnaire.

H0: There is no significant relationship between respondent's incomes and challenges in using organic products

Table 3 Comparison between Incomes with challenges in using organic products

Chi-Square Tests			
	Value	Df	Asymptotic Significance(2-sided)
Pearson Chi-Square	17.167[a]	16	.375
Likelihood Ratio	20.815	16	.186
Linear-by-Linear Association	6.289	1	.012

Table 3 shows a Pearson Chi-Square valueof 17.167 at a 5% level of significance. P value is greater than 0.05, hence the null hypothesis is accepted.

Findings from Table 3

There is no significant relationship, and the study suggests that the problems of employing organic products

to overcome customer skepticism about organic products are unrelated to respondents' wealth.*
* The income of respondents is determined by their household income of consumers purchasing organic products through structured questionnaire

Table 4 Contingency Coefficient relationship betweenIncome and challenges in using organic product

Symmetric Measures			
		Value	Approximate Significance
Nominal by Nominal	Phi	.655	.375
	Cramer's V	.328	.375
	Contingency Coefficient	.548	.375

Table 4 demonstrates that the contingency coefficient is 0.548. Since the value ranges from 0.40 to 0.60, this indicates that there is a moderate link between income and obstacles in using organic products to overcome customer skepticism about organic products and respondents' income.

3.2 Karl Pearson Correlation Coefficient

Karl Pearson's coefficient of correlation is defined as a linear correlation coefficient that falls in the value range of -1 to +1. Value of -1 signifies strong negative correlation while +1 indicates strong positive correlation.[9]

HO: There is no significant relationship between reasons of using organic products with strategies of overcoming consumer's skepticism in using organic product.

Table 5 Correlation between reasons of using organic product with strategies of overcoming consumer's skepticism in using organic product

Pearson Correlation Co-efficient	Transparency	Limited availability	Access	Education	Doubt in health benefit
correlation	.705	.650	.441	.272	.434
Sign.(2-tailed)	.538	0.668	.547	.368	.287

Table 5 reveals that the Karl Pearson's association coefficient is +1, indicating a positive association between the reasons for adopting organic goods and the solutions for overcoming consumer skepticism about organic products. As a result, the analysis shows that the variables are all trending in the same direction.

Findings from Karl Pearson Coefficient Of Correlation

The Karl Pearson's Correlation coefficient is +1, indicating a positive relationship between the reasons for utilizing organic goods and the tactics for overcoming consumer skepticism about organic products.

3.3 Suggestions

By applying these suggestions, marketers may effectively minimize customer mistrust about organic products, develop trust, and encourage sustainable consumption habits.

1. To lessen customer mistrust about organic products, marketers can increase transparency by assuring clear, informative labelling that details ingredients, sourcing, and certification criteria, as well as giving extensive supply chain information.
2. Educating customers about the benefits and distinctions of organic goods through campaigns, workshops, and seminars is critical for building trust.
   Addressing pricing perceptions entails clearly expressing the extra value of organic

4. Conclusion

Consumer distrust about organic foods poses a big challenge to the organic food business. However, by using effective sustainable marketing techniques such as transparency, communication, education, and accessibility programs, it is feasible to overcome these barriers and increase consumer trust and acceptance of organic food products.

Consumer distrust of organic products is a significant barrier for marketers seeking to promote sustainable consumption behaviors. First, transparency may be considerably increased by clearly labelling organic products and disclosing the whole production chain. This increases trust by allowing customers to understand the origins and authenticity of the products they are purchasing. To further strengthen confidence, trustworthy certifying bodies must be used, as well as third-party audits to validate organic claims on an ongoing basis. Educational initiatives are also important. Launching campaigns, workshops, and seminars that emphasize the benefits and contrasts between organic goods. Resulting in greater adoption, consumption of organic product and support for sustainable agriculture practices helps to increase health conscious and make a way to achieve a low-carbon society.

Acknowledgement

I will give thanks to you, LORD, with all my heart; I will tell of all your wonderful deeds. I express my sincere thanks to **Rev. Sr. Dr. Kulandai Therese, Secretary,** Nirmala College for Women, Coimbatore for the consent and encouragement in accomplishing my research work. I extremely Thankful to **Rev. Sr. Dr. Mary Fabiola, Principal,** Nirmala College for Women, Coimbatore, for constantmotivation and also providing the required facilities to complete the research paper successfully.

I express my sincere thanks to **Rev. Sr. Dr. Emelda Mary, Vice Principal**, Nirmala College for Women, Coimbatore, for her constant guidance and support in all my research work. I owe my deep gratitude to **Dr. A. Elizabeth, Head of the Department, Department of Commerce,** Nirmala College for Women, Coimbatore, for her valuable suggestions and support throughout the research work. I express my special thanks to **all faculty members** of Department of Commerce for their encouragement.

It gives me immense pleasure in expressing my gratitude to Kasetsart University Sriracha Campus for giving methis great opportunity that enriches myresearch work.

Reference

[1] Schleenbecker, R., & Hamm, U. (2013). Consumers' perception of organic product characteristics. A review. *Appetite*, *71*, 420–429. https://doi.org/10.1016/j.appet.2013.08.020

[2] Hugar, V. (2021). A study on organic farming and consumer preference towards organic food products. *International Journal of Advances in Engineering and Management (IJAEM)*, *3*, 1084. https://doi.org/10.35629/5252-030910841091

[3] Feil, A. A., Cyrne, C. C. da S., Sindelar, F. C. W., Barden, J. E., & Dalmoro, M. (2020). Profiles of sustainable food consumption: Consumer behavior toward organic food in southern region of Brazil. *Journal of Cleaner Production*, *258*(March,2021). https://doi.org/10.1016/j.jclepro.2020.120690

[4] Eyinade, G. A., Mushunje, A., & Yusuf, S. F. G. (2021). The willingness to consume organic food: A review. *Food and Agricultural Immunology*, *32*(1), 78–104. https://doi.org/10.1080/09540105.2021.1874885

[5] Panneerselvam, P., Halberg, N., Vaarst, M., & Hermansen, J. E. (2012). Indian farmers' experience with and perceptions of organic farming. *Renewable Agriculture and Food Systems*, *27*(2), 157–169. https://doi.org/10.1017/S1742170511000238

[6] Wojciechowska-Solis, J., & Barska, A. (2021). Exploring the preferences of consumers' organic products in aspects of sustainable consumption: The case of the polish consumer. *Agriculture (Switzerland)*, *11*(2), 1–17. https://doi.org/10.3390/agriculture11020138

[7] https://www.bmj.com/about-bmj/resources-readers/publications/statistics-square-one/8-chi-squared-tests

[8] https://www.statisticshowto.com/

[9]https://en.wikipedia.org/wiki/Main_Page

The Ethical Mosaic: Interweaving Ben Mezrich's *The Accidental Billionaires* and Ethical Synergy of Corporate Management and Involvement in Contemporary Society

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Abstract

Social Business, an emergent paradigm of the twenty-first century, intricately weaves traditional commercial practices with a profound commitment to social and environmental objectives. This paper delves into the nuanced interplay between the evolution of social business, user management, and user engagement, as illustrated through the groundbreaking narrative of Facebook's growth depicted in Ben Mezrich's *The Accidental Billionaires* (2009). It examines the founders' journey in transmuting a collegiate project into a global social media colossus, and how innovation, ambition, and ethical dilemmas intersect within the social business framework. Core themes such as social connectivity, virality, monetization strategies, and the ethical complexities are explored by elucidating the critical importance of user engagement in driving both ethical and business success in the digital age. This study aims to promote transparency, foster user trust, community engagement and enhance ethical frameworks in social business practices through methods such as critical online article reviews, a case study of Facebook's development from *The Accidental Billionaires*, theoretical analysis to uncover ethical insights in user engagement, and an online survey capturing nuanced user preferences and behaviors. The synthesis of these methodologies uncovers critical insights into the ethical dimensions of user management and engagement in social business impacting societal well-being and business sustainability. This discourse underscores the necessity of integrating ethical considerations of the digital age into the synergy of user management with user engagement in social business strategies fostering a more just and equitable digital landscape.

Keywords: Social Business, User management, User engagement, Ethical development, Digital age

1. Introduction

The prominence of user management and engagement in social business is tangentially related through the lens of Facebook's origin story in Ben Mezrich's *The Accidental Billionaires* (2009). Mezrich's depiction serves as a poignant example, illustrating how Facebook's emergence as a social platform for Harvard University students underscores foundational aspects of user management and engagement within the context of social business. The novel highlights how effective user management, including the strategic handling of user interactions and data, was crucial to Facebook's growth and societal impact. Central themes of privacy, user engagement strategies, and ethical considerations surrounding data use are explored, portraying the ethical dilemmas faced by social businesses. These complexities underscore the challenge of balancing innovation with ethical responsibility in a digital landscape that shapes modern social interactions. Additionally, surveys were employed to decode contemporary ethical awareness,

providing insights into how modern users perceive and respond to these ethical challenges.

2. Methods and Surveys

2.1 The Vision of Social Business: Tackling Critical Issues

Social business, as envisioned by Nobel Peace Prize laureate Muhammad Yunus, the founder of Grameen Bank, transcends simple definitions, aiming to tackle critical social, economic, and environmental issues like hunger, homelessness, illness, pollution, and ignorance. This approach not only provides underprivileged populations with essential resources and services but also integrates them into the workforce. The increasing involvement of multinational corporations in social business marks a significant trend in modern corporate practices.

2.1.1 Defining Social Business: Yunus's Perspective

Professor Yunus narrows the concept further as a social business primarily addresses a social issue, operates with financial self-sufficiency, and does not distribute dividends to its owners. Instead of one-time donations, philanthropists can invest in sustainable ventures that yield continuous societal benefits, with profits reinvested to expand positive social impact. Several key components are essential for developing a successful social business model. At the heart of this model lies effective user management and engagement, pivotal in navigating ethical challenges and driving sustainable business practices in today's interconnected digital milieu.

2.1.2 Pioneering Social Businesses: Harnessing Technology for Sustainability and Ethical Engagement

In the realm of social business, technology plays a pivotal role in driving sustainability and fostering ethical practices. Grameen Bank, founded by Muhammad Yunus, demonstrates the impactful use of technology in financial inclusion. By managing microloans with advanced systems, the bank supports economic development and empowers underserved communities, showcasing a model of effective and ethical financial management. Fairphone leads the charge in ethical electronics by employing modular design and transparent supply chains. This approach addresses critical issues such as conflict minerals and electronic waste, advocating for a more sustainable and ethical framework within the technology sector. These examples illustrate the profound impact that strategic technological applications can have in promoting sustainability and ethical engagement. Through their innovative approaches, Grameen Bank and Fairphone exemplify how technology can be harnessed to drive positive social and sustainable change, setting standards for future endeavors in the social business landscape.

2.2 Intricacies of User Management and Engagement

User management involves the secure and efficient administration of user accounts, including features like detailed privacy settings, easy password recovery, two-factor authentication, regular activity logs, and customizable notifications. Engagement focuses on fostering meaningful interactions through elements such as interactive content, real-time notifications, community forums, gamification, and live customer support. These strategies are crucial for enhancing user satisfaction, improving platform performance, and building long-term user loyalty.

2.2.1 User Management: Security, and Optimization

User Management (UM) intricately administers user accounts and their access to IT resources, including devices, applications, systems, networks, SaaS services, and storage. As a fundamental element of identity and access management (IAM), it empowers administrators to meticulously control user permissions and security. Within an organization, administrators undertake several key responsibilities:

- Security and Compliance: By managing roles and permissions, administrators ensure that access controls align with security policies and compliance requirements, safeguarding sensitive information.
- Resource Optimization: Efficient management of user access helps optimize the utilization of IT resources, reducing costs and improving system performance.

2.2.2 User Engagement: Interaction and Value

User Engagement refers to the depth of interaction, involvement, and emotional connection users have with a product, service, or platform. It is a multidimensional concept that goes beyond mere usage, encompassing the overall experience and satisfaction users derive from their interactions. Effective user engagement strategies aim to foster a meaningful relationship between the user and the platform, which in turn drives business success. Key dimensions of user engagement include:

- Interaction Metrics: This involves tracking a range of user activities such as website visits, content consumption, time spent on the platform, participation in discussions, feedback sharing, and purchases.
- Value Perception: This dimension assesses how users perceive the value of their interactions with the platform. It involves evaluating user satisfaction, fulfillment, and the perceived benefits they receive.

2.3 Mastering Strategic User Management: A Case Study in Ben Mezrich's *The Accidental Billionaires*

The illumination of how strategic management of user interactions can drive both business success and societal change in Ben Mezrich's *The Accidental Billionaires* notable. The novel underscores the importance of ethical frameworks in maintaining trust and sustainability in digital platforms. Mark Zuckerberg and his cohorts transformed a dormitory project into a global phenomenon, revolutionizing social connectivity and digital engagement while grappling with ethical responsibilities inherent in managing vast user data and influencing societal behaviors. Zuckerberg's vision to connect people globally resonates with the principles of social business, where profitability intertwines with enhancing societal welfare through digital connectivity. Under Zuckerberg's leadership, Facebook quickly scaled into a global phenomenon, serving as a compelling backdrop to explore the interplay between user management, user engagement, and ethical considerations within the evolving realm of social business.

2.3.1 Ethical Governance and User Management

Effective user management is the cornerstone of ethical governance in social business, a theme vividly explored in Mezrich's narrative. The novel chronicles Facebook's nascent days, highlighting the critical importance of managing user interactions, safeguarding data privacy, and adhering to regulatory frameworks Initially conceived by Mark Zuckerberg and his co-founders to connect Harvard students, Facebook aimed to facilitate social interactions within a closed community. "We're gonna call it Harvard Connections," he began, getting right to the point. He tried to keep it simple, (73), this early emphasis on user management was evident in the meticulous oversight of membership and user interactions. By fostering a secure and connected environment, Facebook rapidly gained attraction. This strategic management of user interactions cultivated a vibrant and active community, demonstrating how thoughtful user management can significantly enhance engagement and trust.

2.3.2 Security, Compliance, and Data Privacy

The involvement of aligning access controls with security policies and compliance

requirements, safeguarding sensitive information is inevitable in user management. Mezrich's account highlights the paramount importance of data privacy as Facebook scaled. As the platform expanded beyond Harvard, robust security measures became essential to protect user data and maintain trust. This phase underscored the challenges of scaling a social platform while ensuring the privacy and security of an ever-growing user base. The implementation of comprehensive security protocols was vital in mitigating risks and upholding user confidence.

2.3.3 Proactive Protection: Integrating Audits and Monitoring for Robust Security

Regular audits and monitoring of user activities are fundamental components of robust security, crucial for detecting and responding to unauthorized access or suspicious behavior. These practices involve scrutinizing user interactions and system behaviors to identify and mitigate potential threats before they escalate. In the early days of Facebook, Mezrich's narrative highlights how the company's commitment to constant vigilance was essential in safeguarding the platform's integrity. Facebook implemented rigorous monitoring protocols to oversee user activities, ensuring that any unusual or unauthorized actions were swiftly identified and addressed. The concept of robust security extends beyond just monitoring. It includes a comprehensive approach involving encryption to protect data, authentication mechanisms to verify identities, and access control policies to restrict user privileges. Regular audits complement these security measures by providing ongoing evaluations of system defenses and user access controls. By integrating continuous auditing and monitoring with advanced security protocols, Facebook could effectively manage and mitigate security risks, thereby reinforcing its commitment to a trustworthy platform.

2.4 Mark Zuckerberg's Strategic Enhancements in User Engagement and Theoretical Analysis of Ben Mezrich's *The Accidental Billionaires*

2.4.1 The Evolution of User Engagement: Insights from Facebook's Early Days

Facebook's inception marked a transformative era in digital connectivity, initially targeting Harvard University students to foster social interactions through a digital platform. Mark Zuckerberg's vision centered on enhancing social connectivity through an intuitive interface, fundamentally shaping user engagement strategies that would redefine social media dynamics. Mezrich's narrative unveils Zuckerberg's strategic decisions that propelled Facebook's rapid expansion and revolutionized user engagement dynamics. The platform's agility in integrating user feedback and technological advancements played a pivotal role in its evolution.

2.4.2 Interaction Metrics

The depiction underscores how Facebook's iterative approach to feature development and user interface design strategically utilized interaction metrics. These metrics, including tracking website visits, content consumption, and user interactions, provided insights essential for refining user engagement strategies. You visited it every day. You came back again and again, adding to your site, changing your pictures, your interests, and most of all, updating your friends. (111), this enhances Zuckerberg's methodical adjustments based on these metrics exemplify the platform's responsiveness to user behaviors and preferences.

2.4.3 Value Perception

Mezrich delves into how Facebook strategically assessed user satisfaction and perceived benefits derived from platform interactions. By offering personalized content recommendations and targeted advertising aligned with user interests, Facebook enhanced its value proposition. Mezrich's narrative highlights the platform's evolution from a simple social networking site to a personalized experience that catered to individual user needs and preferences.

2.5 Ethical Development through Synergy of User Management and User Engagement in the Digital Age

2.5.1 Ethical Advancement via User Management and Engagement

In the contemporary digital landscape, the symbiotic relationship between user management and user engagement emerges as a cornerstone in shaping ethical frameworks within platforms, exemplified in Ben Mezrich's seminal work, The Accidental Billionaires. This intricate synergy not only defines user experiences but also dictates how platforms navigate critical aspects such as data governance, privacy safeguards, and broader societal implications.

2.5.2 Ensuring Trust and Transparency: Balancing Data Utilization with Robust Privacy Protections

Mezrich's meticulous portrayal of user management practices reveal how platforms can establish trust and transparency. By prioritizing user trust through robust data management and clear communication on privacy policies, platforms enhance transparency and ethical standards in digital interactions. Mark and Eduardo's alignment of user management with engaging user experiences emphasizes satisfaction and value perception, reinforcing user confidence in platform integrity. Educating users about their digital rights and responsibilities enhances trust and promotes a culture of transparency. Zuckerberg's early focus on user management and data security established a foundation for ethical governance at Facebook, ensuring meticulous control over user interactions and data handling. Mezrich highlights how these decisions promoted transparency and built user trust. By integrating user engagement strategies with robust security protocols such as advanced encryption and access controls. Facebook balanced data utilization with privacy protection. This approach safeguarded sensitive information and reassured users about data safety. The strategic alignment of trust-building practices, educational initiatives, and rigorous security measures enhances user engagement and loyalty, reinforcing ethical standards within digital platforms.

2.5.3 Mitigating Ethical Dilemmas: Algorithmic Integrity and User Autonomy

Platforms can learn from Mark and Eduardo's early efforts by developing user empowerment tools that prioritize user control over their data and digital footprint. This involves implementing intuitive privacy controls that allow users to manage who can access their information and how it is used. On offering transparent data transparency features, platforms can provide insights into how user data is collected, stored, and utilized, fostering trust and accountability. Ethical development in user engagement includes addressing challenges like algorithmic bias and manipulation risks. Platforms can prioritize algorithmic integrity by designing algorithms that prioritize fairness, transparency, and user control. This approach not only safeguards against the unintended consequences of algorithmic bias but also upholds user trust and societal responsibility as exemplified in Zuckerberg's early initiatives with Facebook.

2.6 Survey Introduction: Understanding Ethical Development in the Digital Age

An online survey is a research method conducted over the internet to collect information and opinions from participants. An online survey, conducted via Google Forms, sought to capture nuanced insights from 30 participants regarding ethical practices, digital sustainability, user management, and engagement features. The survey comprised 20 questions, strategically divided into two segments: 10 questions exploring Ethical Practices and Digital Sustainability, and 10 addressing User Management and Engagement. The questions, designed to probe both situational and experiential aspects, enabled a thorough examination of contemporary attitudes and behaviors. This method efficiently gathers diverse perspectives, particularly from college students and working professionals,

who reflect significant engagement with digital practices. The respondents' combined input offers a comprehensive view of ethical standards and user engagement, highlighting the relevance of these issues across different life stage. This survey provided a rich tapestry of insights into user preferences and their involvement in the evolving digital landscape.

2.6.1 Ethical Practices and Digital Sustainability

In today's digital age, ethical practices and digital sustainability are critical for both individuals and businesses. These concepts involve maintaining moral standards and reducing environmental impact in the digital realm. Ethical practices ensure that companies act with integrity, protect consumer rights, and address risks related to data misuse and environmental harm. Digital sustainability, on the other hand, focuses on minimizing the ecological footprint of digital operations through responsible resource management and sustainable practices. This survey plays a crucial role in uncovering consumer attitudes and behaviors towards these issues. By using this survey method, we gain a deeper understanding of the complexities surrounding ethical development in the contemporary digital landscape and how it impacts digital sustainability. This insight helps companies align with consumer expectations, enhance transparency, and build trust in the digital marketplace.

2.6.2 User Management and Engagement

User Management and Engagement are critical components in the digital realm, shaping how individuals interact with and perceive digital platforms. User management involves the strategic administration of user accounts and their access to various digital resources, such as applications, data, and services. User engagement, on the other hand, focuses on fostering meaningful interactions between users and digital platforms. It encompasses features that enhance user experience, such as interactive content like polls and quizzes, real-time notifications and responsive customer support. This survey seeks to provide valuable insights into these areas, revealing the current levels of awareness among digital platform users regarding user management and engagement practices. By exploring these insights, the survey aims to enhance user satisfaction, optimize platform performance, and foster long-term user loyalty.

3. Results and Discussions

3.1 The Synergy of User Management, Engagement, and Ethical Development of the Digital Age

3.1.1 Importance of User Management and Engagement in Modern Social Businesses

User management and engagement are cornerstones of success in today’s digital businesses. Mark Zuckerberg’s story in *The Accidental Billionaires* reveals how adept user management can fuel technological innovation and societal impact, showcasing a delicate balance between advancing technology and upholding ethical standards. Zuckerberg’s focus on transparency and data security-built user trust and fostered engagement, while Fairphone’s commitment to sustainable practices and ethical sourcing resonates with users who prioritize responsibility. Both Mark Zuckerberg’s approach and Fairphone’s model illustrate how effective user management and ethical practices drive success in modern social businesses.

3.1.2 Strategic Role of User Engagement in Platform Growth and Ethical Considerations

Facebook's early evolution underscores the strategic significance of user engagement in fostering platform adoption and sustainable growth. Mezrich's description provides insights into the iterative development of user engagement strategies and the ethical dimensions of digital stewardship. Understanding these dynamics is crucial for businesses aiming to craft effective strategies that enhance user engagement while

navigating ethical challenges in digital ecosystems. The portrayal of Facebook's platform growth underscores as, Hopefully, somehow, competing with thefacebook, MySpace, Friendster, and all the other social networks that were already moving forward, spreading like viruses across the World Wide Web. (161), that played the pivotal role of ethical development in shaping user experiences and building trust within digital platforms.

3.1.3 Ethical Complexities and Business Imperatives in Digital Engagement

Ben Mezrich's exploration highlights the ethical complexities inherent in managing user interactions and engagement on digital platforms like Facebook. Businesses must prioritize ethical considerations alongside technological advancements to build sustainable digital communities founded on trust, transparency, and ethical integrity. By examining Zuckerberg's strategic decisions and their ethical implications, the narrative emphasizes the importance of ethical development in shaping user-centric experiences and fostering transparency within digital ecosystems.

3.2 Analysis of Survey Responses in Ethical Practices and Digital Sustainability

3.2.1 Effectiveness of digital platforms Addressing Ethical Sustainability

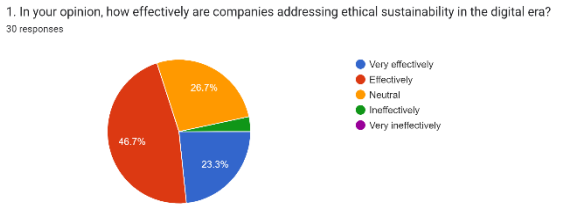

Figure 1 Effectiveness of digital platforms Addressing Ethical Sustainability

- Very Effectively (23.3%)
- Effectively (26.7%)
- Neutral (46.7%)
- Ineffectively (0%)
- Very Ineffectively (3.3%)

Analysis: The majority of respondents are neutral, indicating a significant uncertainty or ambivalence towards how effectively companies address ethical sustainability. A relatively equal distribution between “very effectively” and “effectively” shows some positive perception, but the presence of neutrality suggests that companies might need to improve transparency and communication about their ethical practices. The analysis uses various methods, including pie charts, to effectively visualize and interpret the data.

3.2.2 Aspects of Ethical Sustainability that are Most Concerning

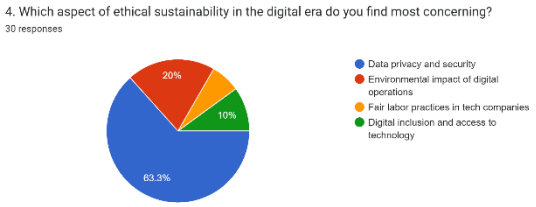

Figure 2 Aspects of Ethical Sustainability that are Most Concerning

- Data privacy and security (63.3%)
- Environmental impact of digital operations (10%)
- Fair labor practices in tech companies (20%)
- Digital inclusion and access to technology (6.7%)

Analysis: Data privacy and security are the top concerns for the majority of respondents, which reflects the current global emphasis on data protection and privacy regulations. Concerns about fair labor practices and the environmental impact show that ethical practices in operations and employment are

also significant for a notable proportion of respondents.

3.2.3 Importance of Knowing How a Company Handles Data Privacy and Security

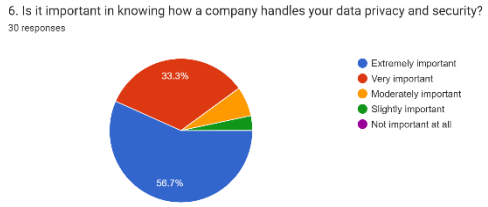

Figure 3 Importance of Knowing How a Company Handles Data Privacy and Security

- Extremely important (56.7%)
- Very important (33.3%)
- Moderately important (6.7%)
- Slightly important (3.3%)
- Not important at all (0%)

Analysis: A vast majority (90%) of respondents consider data privacy and security as extremely or very important. This underscores the critical role data protection plays in digital sustainability. Only a small fraction views it as moderately or slightly important, showing that most consumers prioritize their data security.

3.2.4 Willingness to Stop Using a Digital Platform if Engaged in Unethical Practices

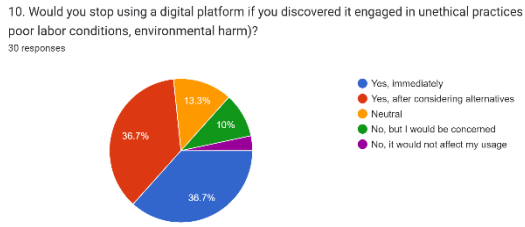

Figure 4 Willingness to Stop Using a Digital Platform if Engaged in Unethical Practices

- Yes, immediately (36.7%)
- Yes, after considering alternatives (36.7%)
- Neutral (13.3%)
- No, but I would be concerned (10%)
- No, it would not affect my usage (3.3%)

Analysis: A significant portion (73.4%) would stop using a platform immediately or after considering alternatives if unethical practices are discovered. This indicates a strong consumer preference for ethical behavior in digital platforms.

The neutrality and slight concern among others suggest that while not everyone would act immediately, unethical practices still influence consumer trust and perception.

3.3 User Management and Engagement Survey Analysis

3.3.1 Most Valued User Management Feature

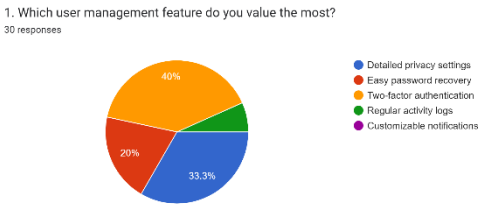

Figure 5 Most Valued User Management Feature

- Detailed privacy settings (33.3%)
- Easy password recovery (20%)
- Two-factor authentication (40%)
- Regular activity logs (6.7%)
- Customizable notifications (0%)

Analysis: The majority of respondents (40%) value two-factor authentication the most, emphasizing the importance of enhanced security measures. Detailed privacy settings are also highly valued (33.3%), highlighting the need for customizable and comprehensive control over personal data. Easy password recovery (20%) indicates a need for user-friendly mechanisms to manage account access. The lack of value placed on customizable notifications (0%) implies that users may prioritize fundamental security and privacy features over personalization options in user management.

3.3.2 Frequency of Using Feedback Mechanisms

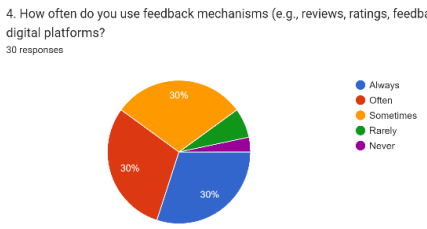

Figure 6 Frequency of Using Feedback Mechanisms

- Always (30%)
- Often (30%)
- Sometimes (30%)
- Rarely (6.7%)
- Never (3.3%)

Analysis: With 90% of respondents using feedback mechanisms frequently, it is clear that users are actively engaged in providing feedback. Only a small fraction use these mechanisms rarely (6.7%) or never (3.3%), showing that most users recognize the value of providing feedback on digital platforms. Digital platforms should leverage this engagement by making feedback processes easy to access and use, and by acting on user feedback to improve services.

3.3.3 Frequency of Reviewing and Updating Privacy Settings

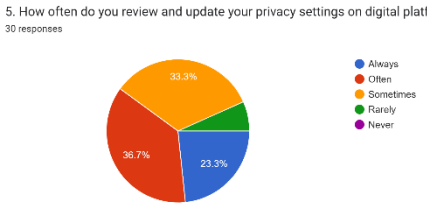

Figure 7 Frequency of Reviewing and Updating Privacy Settings

- Always (23.3%)
- Often (36.7%)
- Sometimes (33.3%)
- Rarely (6.7%)
- Never (0%)

Analysis: A combined 93.3% of respondents review and update their privacy settings always, often, or sometimes. This indicates a high level of awareness and proactive behavior regarding privacy management. Only a small fraction rarely updates their privacy settings, and no respondents never update them, highlighting the importance users place on maintaining their privacy. The high frequency of users reviewing and updating their privacy settings (93.3%) reflects proactive engagement with privacy management. This behavior indicates that users are highly engaged with their personal data and take active steps to protect their privacy.

3.3.4 Satisfaction with Customer Support for Managing Account Issues

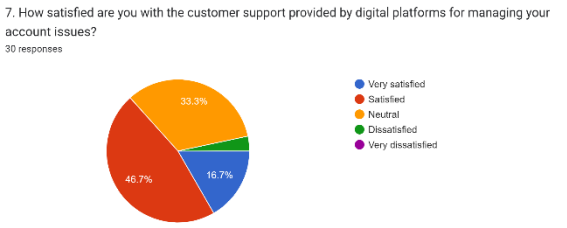

Figure 8 Satisfaction with Customer Support for Managing Account Issues

- Very satisfied (16.7%)
- Satisfied (46.7%)
- Neutral (33.3%)
- Dissatisfied (3.3%)
- Very dissatisfied (0%)

Analysis: The analysis, depicted using a pie chart, reveals that the majority of respondents (63.4%) are satisfied or very satisfied with the customer support provided by digital platforms for managing account issues. A notable portion (33.3%) remains neutral, indicating that while customer support is generally adequate, there is potential for improvement. The high percentage of satisfaction suggests that users typically have positive experiences when addressing account issues. The pie chart effectively illustrates the distribution of responses,

providing a clear visual representation of user sentiment and highlighting areas where enhancements could be made. This method is particularly efficient for this online survey, as it allows for a straightforward interpretation of user feedback and aids in identifying key trends and areas for improvement in customer support.

4. Conclusion

In the realm of social business, addressing critical issues hinges on adeptly managing user interactions and fostering engagement. User management forms the bedrock of this endeavor, encompassing the administration, security, and optimization of user accounts. It ensures operational efficiency and safeguards user trust through meticulous attention to data security and privacy. Ben Mezrich's portrayal in *The Accidental Billionaires* vividly illustrates how Mark Zuckerberg's strategic enhancements in user engagement shaped Facebook's trajectory. Through iterative improvements and visionary insights, Zuckerberg revolutionized digital interaction, emphasizing the pivotal role of user engagement in platform evolution. Survey methodologies have illuminated consumer sentiments on ethical practices and digital sustainability in the digital age. They reveal a resounding preference for transparency and ethical responsibility, underscoring how these factors influence consumer trust and loyalty.

At the heart of these discussions lies the synergy between user management, engagement strategies, and ethical development. By integrating robust user management practices with compelling engagement features, platforms not only enhance user satisfaction but also uphold ethical standards. This approach fosters enduring relationships with users, positioning businesses as stewards of trust and integrity in the digital realm. Thus, Ethical development is not merely complementary but essential in the digital age which forges technology to serve humanity's broader interests and to contribute a sustainable and inclusive livelihood. The necessity of integrating ethical considerations into the synergy of user management with user engagement in social business strategies fostering a more just and equitable digital landscape. the confluence of strategic user management, innovative engagement tactics, and ethical diligence emerges as a cornerstone of sustainable social digital business. It signifies a dedication not only to fulfilling user expectations but also to shaping a digital landscape anchored in ethical principles and user-centric values, thereby paving the way for sustainable digital platform and social business practices.

Reference

[1] Mezrich, Ben. *The Accidental Billionaires*. 2009. Arrow Books, 2010. Print.

[2] Yunus, M., Dalsace, F., Menascé, D., & Faivre-Tavignot, B. (2015). *Reaching the rich world's poorest consumers*. Harvard Business Review, 93(3).

[3] Monique. "Don't read our 2023 Impact Report. Read this instead". 07 June 2024. https://rb.gy/uhe3g5

[4] "Report 2022: Investing Today for a Better Tomorrow". Grameen Foundation. 29 June 2024. https://rb.gy/ekf05b

[5] Soni, Rakesh. "What is User Management?". 16 March 2021. https://rb.gy/c50moc

[6] Trymata. "What is User Engagement? Definition, Metrics and Strategy". 24 April 2024. https://rb.gy/xfo1rp

Model of Consumers' Re-Purchase Intention for Social Enterprises' Products in Beijing, China: A Perspective on Social Enterprise Product Association

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Abstract
The research objectives were as follows: 1) to study the influence of social enterprise product associations on the sensory satisfaction and cognitive stimulation of consumers in Beijing, China; 2) to study the influence of sensory satisfaction and cognitive stimulation on consumers' re-purchase intentions for social enterprise products in Beijing, China; and 3) to develop consumers' re-purchase intentions model for social enterprises' products in Beijing, China. This research adopted mixed methods approach, The quantitative research to collected 249 valid samples for this survey. The measured results of each fitting index of the CFA model are constructed in this validity test, indicating that the model has a good fit. The SEM model constructed in this hypothesis test has a good fit, and the constructed model is relatively reliable. In qualitative research, the interviewees in this study are mainly Beijing enterprise executives, through a systematic approach, themes emerged that shed light on participants' perspectives and experiences. The research findings revealed that: 1) social enterprise products are perceived to match or exceed traditional businesses in quality. Innovations in quality assurance enhance cognitive stimulation, certifications assure consumers of product quality and ethical standards, boosting sensory satisfaction and trust; 2) emotional satisfaction and alignment with social values deepen sensory satisfaction and cognitive engagement; 3) products' ongoing social impact beyond purchase prompts cognitive stimulation and enhances sensory satisfaction. This research provides robust insights into the complex dynamics of consumer behavior towards social enterprise products in Beijing, contribute to a deeper understanding of how social enterprises can effectively engage consumers, enhance satisfaction, and foster long-term loyalty through strategic alignment with consumer values and quality-driven sensory experiences.
Keywords: Consumers' Re-Purchase Intention, Product Association, Social Enterprise

1. Introduction

As a typical representative of modern public welfare, social enterprise is a new type of social organization that has emerged all over the world in recent years. As a new economic form and organizational model, it has been recognized and accepted by more and more countries. Although there are still differences in the cognition and understanding of social enterprises in different countries [1], on the whole, all walks of life in various countries have basically reached a consensus that social enterprises have the dual nature of business and public welfare.

The emergence of social enterprises provides new ideas and methods to solve the problems of "government failure" and "market failure" in the field of traditional public management. Different from traditional commercial enterprises, social enterprises pay more attention to social responsibility and public welfare value, meet social needs through goods and services, bring social benefits, and achieve economic returns in business operations. Social enterprises usually choose to operate in areas of greater social significance and need to be improved, such as

environmental protection, education, medical care, etc, which need to solve social problems and have the significance of promoting social progress and sustainable development [2]. We can be seen that the establishment time of social enterprises in China is relatively short, still in the early stage of development, and the ability to resist risks and market competitiveness is not strong. On the other hand, social attention is relatively low. Therefore, it is of great significance to study the repurchase pattern of social enterprise products from the perspective of consumers.

Social enterprises in Beijing have emerged prominently as consumer interest in socially responsible products continues to grow. These enterprises are often associated with ethical values, sustainability, and community impact, shaping consumer perceptions. Sensory satisfaction plays a pivotal role as consumers evaluate products based on sensory experiences such as taste, touch, and smell, influencing their overall satisfaction and likelihood of repeat purchases. Furthermore, cognitive processes, including perceptions of value and ethical considerations, are stimulated by these products, underscoring the multifaceted nature of consumer responses to social enterprise offerings. Despite the significance of sensory and cognitive factors, empirical research specific to their impact on consumer behavior towards social enterprise products in Beijing remains limited. Existing models fail to comprehensively integrate sensory satisfaction and cognitive stimulation within the context of social enterprises, presenting a notable gap in understanding the drivers of consumer engagement and loyalty [3].

The sustainability and growth of social enterprises in Beijing hinge significantly on consumer re-purchase intentions, which reflect ongoing loyalty and satisfaction beyond initial product trials. Behavioral economics principles suggest that sensory satisfaction, encompassing hedonic experiences, and cognitive stimulation, involving evaluative processes, profoundly influence consumer decision-making. Understanding these dynamics is crucial for predicting and fostering repeat purchases of socially responsible products, thereby bolstering the market presence of social enterprises. Despite their critical role, studies directly linking sensory and cognitive experiences to re-purchase intentions among Beijing's social enterprises remain sparse. A nuanced exploration of how these factors interplay to drive consumer behavior towards sustainable purchasing choices is imperative to bridge existing research gaps and inform targeted marketing strategies [4].

The development of a robust model is pivotal in elucidating and predicting consumer behavior towards social enterprise products in Beijing. This model must integrate various factors, including sensory satisfaction, cognitive stimulation, and potentially other variables such as brand perception and social impact awareness, into a cohesive framework. Insights gleaned from such a model can offer practical guidance for enhancing marketing strategies and refining product development initiatives tailored to the unique dynamics of Beijing's social enterprise sector [5]. However, the current landscape reveals a paucity of established models specifically tailored to forecast re-purchase intentions within Beijing's social enterprise context. This gap presents an opportunity to contribute to theoretical frameworks that comprehensively address the distinctive facets of consumer behavior towards socially responsible products.

The burgeoning interest in understanding consumer behavior towards social enterprise products in Beijing underscores a critical focus on sensory satisfaction, cognitive stimulation, and their pivotal roles in shaping re-purchase intentions. Addressing these research gaps promises valuable insights that can bolster consumer engagement and sustain competitive advantage for social enterprises amidst Beijing's evolving consumer landscape.

2. Objectives

1. To study the influence of social enterprise product associations on the sensory satisfaction and cognitive stimulation of consumers in Beijing, China.
2. To study the influence of sensory satisfaction and cognitive stimulation on consumers' re-purchase intentions for social enterprise products in Beijing, China.
3. To develop consumers' re-purchase intentions model for social enterprises' products in Beijing, China.

3. Literature review

3.1 Influence of social enterprise product associations on sensory satisfaction and cognitive stimulation

Social enterprises are gaining momentum globally, notably in Beijing, China, where consumer preferences increasingly hinge on ethical considerations and community impact. Within this context, product associations play a pivotal role in shaping consumer perceptions of social enterprise offerings, influencing both sensory satisfaction and cognitive stimulation.

Social enterprise products are often linked with ethical values, sustainability practices, and community support. Functional associations, emphasizing durability and utility, bolster sensory satisfaction by meeting expectations of quality and reliability. Emotional associations, tied to empathy and altruism, enhance sensory satisfaction through positive emotional responses [6]. Symbolic associations, signaling status or identity, foster cognitive stimulation by reinforcing consumer beliefs and values. Social associations, focusing on community impact and social responsibility, deepen cognitive stimulation by aligning consumer choices with broader societal values [7]. While existing literature recognizes the impact of product associations on consumer perceptions, empirical studies specifically investigating their influence on sensory satisfaction and cognitive stimulation within Beijing's social enterprises remain scarce. This research gap underscores the need for deeper exploration into how various types of product associations shape consumer behavior in this unique market setting.

3.2 Influence of sensory satisfaction and cognitive stimulation on re-purchase intentions

Consumer re-purchase intentions serve as crucial indicators of loyalty and satisfaction [8]. Sensory satisfaction, derived from positive product experiences, reinforces perceptions of quality and enjoyment, thereby enhancing consumer loyalty [9]. Cognitive stimulation, arising from reflective evaluation and alignment with personal values, influences consumer decisions by fostering a deeper connection with the product's purpose and impact [10]. From a behavioral economics standpoint, sensory satisfaction reflects hedonic experiences that drive consumer preferences based on immediate sensory gratification [11]. Cognitive stimulation involves evaluative processes where consumers weigh long-term benefits and ethical implications, shaping their purchasing decisions [12]. Despite theoretical insights into sensory satisfaction and cognitive stimulation, empirical research specifically linking these factors to re-purchase intentions for social enterprise products in Beijing remains limited. This gap highlights the necessity for empirical studies that validate these relationships and contribute to the development of predictive models tailored to the intricacies of consumer behavior within social enterprises.

3.3 Development of a re-purchase intentions model for social enterprises' products

Developing a robust model of re-purchase intentions entails integrating factors such as sensory satisfaction, cognitive stimulation, and possibly other variables like brand perception and social impact awareness [13]. Such a model not only aids in forecasting consumer behavior but also informs strategic decisions related to marketing and product development within

social enterprises [14]. While predictive models exist for consumer behavior in diverse contexts, there is a notable absence of established models tailored to predict re-purchase intentions within Beijing's social enterprise sector. This research gap presents an opportunity to introduce innovative frameworks that can effectively guide strategies aimed at enhancing consumer engagement and sustaining market competitiveness for social enterprises. According to the literature review, the conceptual framework is provided in Figure 1.

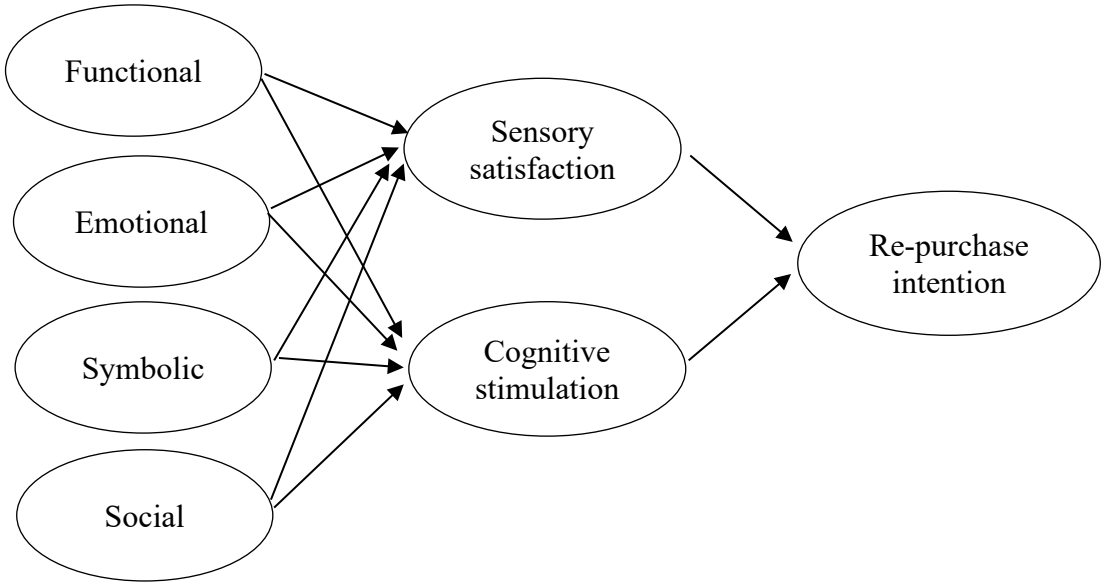

Figure 1.1 Conceptual Framework

This conceptual framework underscores the evolving research landscape on consumer behavior towards social enterprise products in Beijing. It highlights the influential roles of product associations, sensory satisfaction, cognitive stimulation, and re-purchase intentions. Yet, gaps persist in empirical evidence specific to Beijing's social enterprise sector, necessitating rigorous research and model development to enrich strategic decision-making and fortify the sustainability of social enterprises amidst competitive market dynamics.

4. Methodology

4.1 Research design

Quantitative data will be collected using a questionnaire developed based on concepts and theories related to social enterprise product association and re-purchase Intentions, referencing the paper of Choi [15]. Details are provided in the appendix, along with the validation process of the questionnaire. The collected data and information were analyzed, interpreted and then presented in terms of frequency, percentage, mean ($\bar{X}$), standard deviation (SD), and employed the five-point Likert rating scale to assess social enterprise's description of statements. The mean scores as the following: 5 refers to the totally agree, 4 refers to the agree, 3 refers to the fair enough, 2 refers to the disagree, 1 refers to the totally disagree.

4.2 Population and sample size

Approximately$909.1x10^6$ of population. Social enterprise product's customers and other customers in the Chinese

markets. Sample selecting method: random sampling.

Sample size: 400

$$n = \frac{N}{1+Ne^2} = \frac{909.1x10^6}{1+909.1x10^6x0.05^2} \approx 400$$

The qualitative research design will complement the quantitative approach by providing in-depth insights and understanding of consumers' perceptions, attitudes, and experiences related to social enterprise products. This approach will involve interviews data collection method. Through these methods, researchers will explore the nuances of consumers' social enterprise product associations, sensory satisfaction, cognitive stimulation, and re-purchase intentions, allowing for a deeper understanding of the underlying factors and mechanisms at play. I searched for 20 Beijing enterprises, contacting the relevant person in charge of the enterprise, among which 3(A, B, C) Beijing enterprise executives are willing to be interviewed, thematic was use to analyze the qualitative data and identify key themes, patterns, and insights. The qualitative approach will provide rich, context-specific insights that can inform the development and refinement of the quantitative survey instrument and enhance the interpretation of quantitative findings

4.3 Data Collection

Qualitative research, in-depth interviews will be conducted with a subset of consumers to explore their attitudes, perceptions, and experiences related to social enterprise products. Semi-structured interviews will allow for open-ended exploration of topics such as product associations, sensory experiences, and re-purchase intentions, providing rich qualitative data. Quantitative research, the survey was carried out through the online platform Wenjuanxing, which involved a total of 400 people and not all of them are the social enterprise's customers. Structured surveys will be administered to a sample of consumers in Beijing, China, to collect quantitative data on their social enterprise product associations, sensory satisfaction, cognitive stimulation, and re-purchase intentions. The survey will include validated scales and items to measure each construct, ensuring reliability and validity. Surveys can be distributed online, through email invitations, or in-person interviews.

4.4 Data Analysis

Qualitative research, rhematic analysis will be employed to identify recurring themes, patterns, and concepts emerging from the in-depth interviews. Researchers will systematically analyze the qualitative data to identify key themes related to attitudes, perceptions, and experiences regarding social enterprise products, including product associations, sensory experiences, and re-purchase intentions. Quantitative research will employ descriptive statistics, such as means, standard deviations, and frequencies, to summarize the quantitative data obtained from the structured surveys. This analysis will provide an overview of the distribution and central tendencies of variables related to social enterprise product associations, sensory satisfaction, cognitive stimulation, and re-purchase intentions. Structural equation modeling (SEM) is a multivariate statistical technique that combines factor analysis and path analysis. Its strength lies in the quantitative study of the interaction between multiple variables. This paper's data analysis was used SEM.

5. Result

5.1 Qualitative result

Based on the analysis of interview data, it can be summarized to the influence of social enterprise product associations on sensory satisfaction, cognitive stimulation, and their impact on consumers' re-purchase intentions for social enterprise products in Beijing, China is depicted in Table 1.

Table 1 Summaries interview data analysis result

Issues	Summary
Product quality and performance	Social enterprise products are perceived to match or exceed traditional businesses in quality. Innovations in quality assurance enhance cognitive stimulation.
Certifications and standards	Certifications assure consumers of product quality and ethical standards, boosting sensory satisfaction and trust.
Emotional connection and value alignment	Emotional satisfaction and alignment with social values deepen sensory satisfaction and cognitive engagement.
Extended social impact	Products' ongoing social impact beyond purchase prompts cognitive stimulation and enhances sensory satisfaction.

The influence of social enterprise product associations on sensory satisfaction and cognitive stimulation of consumers in Beijing, China is profound. Consumers perceive social enterprise products to offer high quality and performance comparable to traditional businesses, emphasizing innovative approaches and adherence to certifications and standards. This focus enhances sensory satisfaction and cognitive stimulation, crucially impacting consumers' re-purchase intentions by building trust and loyalty based on perceived product quality and ethical standards. Sensory satisfaction, rooted in confidence in product quality, and cognitive stimulation, driven by engagement with ethical implications, significantly influence consumers' decisions to re-purchase social enterprise products in Beijing. This dual assurance, supported by emotional connections and value alignment, fosters a deeper consumer commitment to social causes and enhances the overall consumer experience, validating hypotheses within the research framework and highlighting the complex dynamics shaping consumer behavior in this market. As through the video number, public number, small red book and other platforms to carry out network publicity.

5.2 Quantitative result

The structural equation model also adopts the idea of verification to test the relationship of each path, so the fit test should be carried out first for the constructed model. As can be seen from the test results in Table 2, among the measured results of each fitting index, the NFI result is 0.894, which does not reach the excellent level above 0.9, but is within the acceptable range above 0.85. The measured results of other indicators are in the excellent range, so the SEM model constructed in this hypothesis test has a good fit, and the constructed model is relatively reliable. Structural equation model of each path relationship test as show in Table 3.

Table 2 Model fit test

Fitting Index	Reference Standard	Measured Result
CMIN/DF	1-3 Excellent，3-5Good	1.446
RMSEA	<0.05Excellent，<0.08Good	0.042
NFI	>0.9	0.894
IFI	>0.9	0.965
TLI	>0.9	0.959
CFI	>0.9	0.964

Table 3 Structural equation model of each path relationship test

Path Relationship			B	β	S.E.	C.R.	P
Sensory Satisfaction	<---	Functional	0.220	0.206	0.072	3.057	0.002
Cognitive stimulation	<---	Functional	0.262	0.242	0.072	3.631	***
Sensory Satisfaction	<---	Emotional	0.312	0.250	0.087	3.564	***
Cognitive stimulation	<---	Emotional	0.411	0.326	0.089	4.616	***
Sensory Satisfaction	<---	Symbolic	0.373	0.314	0.084	4.421	***
Cognitive stimulation	<---	Symbolic	0.339	0.282	0.083	4.086	***
Sensory Satisfaction	<---	Social	0.197	0.207	0.064	3.097	0.002
Cognitive stimulation	<---	Social	0.229	0.237	0.064	3.594	***
Re-Purchase Intentions	<---	Sensory_Satisfaction	0.340	0.366	0.069	4.941	***
Re-Purchase Intentions	<---	cognitive_stimulation	0.252	0.274	0.066	3.790	***

Note: *** is p<0.001

According to the path relationship test results in Table 4.10, it can be seen that Functional product associations have a significant positive impact on sensory satisfaction β=0.206, p<0.01, so the corresponding hypothesis H1a is valid.

Functional product associations have a significant positive effect on cognitive stimulation β=0.242, p<0.001, so H1b is assumed to be valid.

Emotional product associations have a significant positive effect on sensory satisfaction β=0.25, p<0.001, so H2a was assumed to be valid.

Emotional product associations have a significant positive effect on cognitive stimulation β=0.326, p<0.001, so H2b was assumed to be valid.

Symbolic product associations have a significant positive effect on sensory satisfaction β=0.314, p<0.001, so the hypothesis H3a is valid.

Symbolic product associations have a significant positive effect on cognitive stimulation β=0.282, p<0.001, so the hypothesis H3b is valid.

Social product associations have a significant positive effect on sensory

satisfaction, β=0.207, p<0.01, so hypothesis H4a is valid.

Social product associations have a significant positive effect on cognitive stimulation β=0.237, p<0.001, so hypothesis H4b is valid.

Sensory satisfaction has a significant positive effect on repurchase intention β=0.366, p<0.001, so hypothesis H5 is valid.

Cognitive stimulation has a significant positive effect on repurchase intention β=0.274, p<0.001, so hypothesis H6 is valid.

According to the test results, it can be seen that through the model test, all the hypothesis relationships proposed in this study are valid, and the variables are promoting relationships. Consumers' re-purchase intentions model for social enterprises' products in Beijing, China as shows in Figure 2.

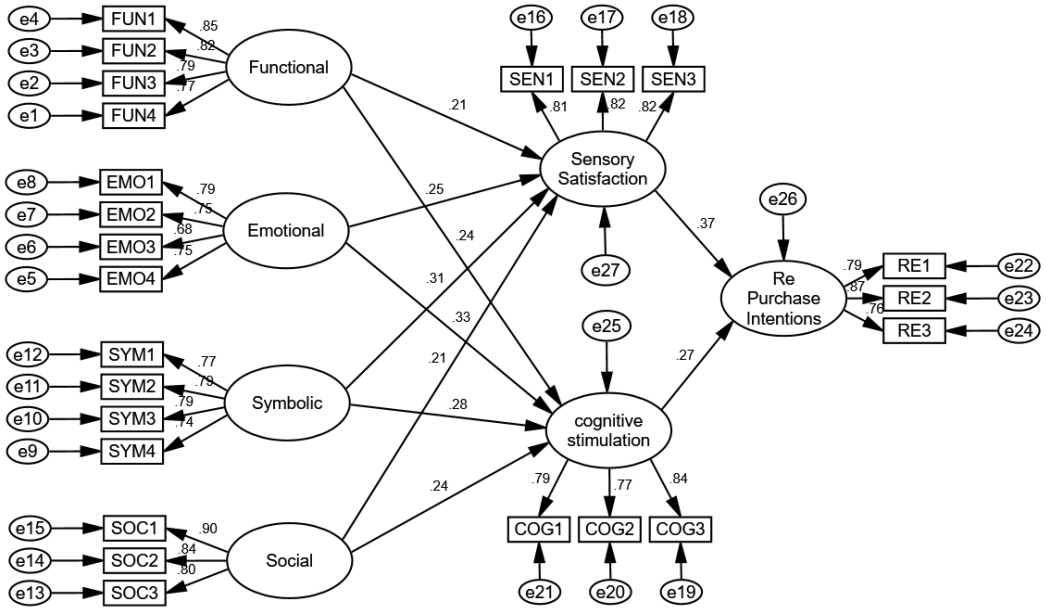

Figure 2 Consumers' re-purchase intentions model for social enterprises' products in Beijing, China

The model for predicting consumers' re-purchase intentions of social enterprise products in Beijing integrates sensory satisfaction, cognitive stimulation, and their respective influences. Quality-driven sensory experiences and emotional connections increase satisfaction levels, thereby positively influencing cognitive engagement with product values and societal impact. This cognitive engagement, in turn, strengthens consumers' intentions to repurchase, driven by a desire to maintain positive experiences and support social missions. The model emphasizes the interconnectedness of sensory and cognitive factors in shaping consumer behavior, offering insights for strategic marketing and product development in the competitive Beijing market.

5. Discussion and conclusion

5.1 Discussion

The findings underscore the significant impact of social enterprise product associations on sensory satisfaction and cognitive stimulation in Beijing. Products associated with functional, emotional, symbolic, and social attributes are shown to enhance sensory satisfaction by meeting

quality expectations and eliciting positive emotional responses. This aligns with previous research suggesting that sensory satisfaction is intricately tied to perceived product quality and emotional resonance [16]. Moreover, the stimulation of cognitive engagement through these associations reflects a deeper connection with consumer values and societal expectations. This is supported by studies highlighting the role of cognitive processes in consumer decision-making and the importance of value alignment in enhancing product relevance and appeal [17]. The emphasis on quality, innovation, and social impact within these associations not only fosters positive consumer perceptions but also strengthens the overall consumer-brand relationship.

The research identifies sensory satisfaction and cognitive stimulation as pivotal factors influencing consumers' re-purchase intentions for social enterprise products in Beijing. Positive sensory experiences, driven by perceived quality and emotional satisfaction, are found to enhance consumer loyalty and satisfaction. This echoes studies emphasizing the critical role of sensory experiences in shaping consumer preferences and loyalty behaviors [18]. Cognitive stimulation arising from meaningful product interactions and alignment with personal values reinforces consumers' commitment to repurchasing. This aligns with theories of cognitive dissonance and consumer behavior, suggesting that consistent positive experiences and alignment with values reduce post-purchase dissonance and increase repeat purchase likelihood [19]. Together, these findings highlight the holistic nature of consumer experiences and underscore the importance of integrating sensory and cognitive dimensions in fostering long-term consumer relationships.

The proposed model for predicting consumers' re-purchase intentions integrates sensory satisfaction and cognitive stimulation, emphasizing their interconnected influences on consumer behavior. Quality-driven sensory experiences and emotional connections are identified as key drivers of satisfaction levels, positively influencing cognitive engagement with product values and societal impact. This resonates with research indicating that emotional and cognitive factors interact to shape consumer attitudes and behaviors [20]. The model suggests that cognitive engagement, fostered by sensory satisfaction and value alignment, plays a crucial role in strengthening consumers' intentions to repurchase social enterprise products. This underscores the dynamic relationship between consumer perceptions, emotional responses, and cognitive evaluations in shaping repeat purchase behaviors [21]. Ultimately, the model offers strategic insights for enhancing consumer satisfaction and loyalty within the competitive Beijing market, emphasizing the need for social enterprises to prioritize both sensory appeal and cognitive resonance in their marketing and product development strategies.

5.2 Conclusion

Social enterprise product associations significantly influence sensory satisfaction and cognitive stimulation among consumers in Beijing. Products associated with functional, emotional, symbolic, and social attributes enhance sensory satisfaction by meeting quality expectations and eliciting positive emotional and symbolic responses. These associations also stimulate cognitive engagement by reinforcing consumer values and aligning with societal expectations. The emphasis on quality, innovation, and social impact within these associations fosters deeper consumer connections, influencing both sensory experiences and cognitive perceptions positively. Sensory satisfaction and cognitive stimulation play crucial roles in shaping consumers' re-purchase intentions of social enterprise products in Beijing. Positive sensory experiences, driven by quality perceptions and emotional satisfaction, enhance consumer loyalty and satisfaction.

Meanwhile, cognitive stimulation, arising from meaningful product interactions and alignment with personal values, reinforces consumers' commitment to repurchasing. These factors collectively underline the importance of holistic consumer experiences in driving repeat purchase behaviors within the social enterprise sector in Beijing.

In conclusion, the research provides robust insights into the complex dynamics of consumer behavior towards social enterprise products in Beijing. By exploring the interplay between product associations, sensory experiences, cognitive perceptions, and purchase intentions, the study underscores the multifaceted nature of consumer decision-making within the context of social entrepreneurship. These findings contribute to a deeper understanding of how social enterprises can effectively engage consumers, enhance satisfaction, and foster long-term loyalty through strategic alignment with consumer values and quality-driven sensory experiences. Future research could further explore the nuanced influences of cultural and contextual factors on these relationships, expanding our understanding of global consumer behavior dynamics in socially responsible consumption contexts.

6. Practical implication

1) Social enterprises in Beijing should strategically align their products with functional, emotional, symbolic, and social attributes. This involves not only meeting quality expectations but also eliciting positive emotional responses and reinforcing societal values. By consciously crafting product associations that resonate with consumer aspirations and societal expectations, enterprises can enhance sensory satisfaction and stimulate cognitive engagement. Emphasize the quality and sensory appeal of products to foster positive consumer experiences. This includes ensuring consistency in product quality, packaging, and sensory attributes that align with consumer preferences. Investing in sensory marketing strategies such as appealing aesthetics, tactile experiences, and sensory-enhanced product presentations can significantly enhance sensory satisfaction and differentiate products in the marketplace. Foster emotional connections through storytelling, brand narratives, and transparent communication about social impact. Consumers are more likely to develop loyalty and repurchase intentions when they perceive a genuine commitment to social causes and when emotional resonance is cultivated through authentic brand stories. Social enterprises can leverage emotional branding techniques to deepen consumer engagement and build trust.

2) Align products with consumer values and beliefs to enhance cognitive stimulation. Social enterprises should articulate their mission, values, and impact clearly to resonate with consumer preferences for socially responsible products. By demonstrating a commitment to ethical sourcing, sustainability, and community engagement, enterprises can appeal to consumers who prioritize values-aligned consumption choices. Develop integrated marketing strategies that emphasize both sensory appeal and cognitive resonance. This includes leveraging digital platforms, experiential marketing tactics, and personalized communications to engage consumers on multiple levels. By integrating sensory stimuli with compelling narratives about product benefits and societal contributions, enterprises can enhance brand loyalty and encourage repeat purchases. Collect and analyze consumer feedback to continuously refine product offerings and marketing strategies. Implementing mechanisms for gathering consumer insights, such as surveys, focus groups, and social media monitoring, can provide valuable feedback on sensory experiences, emotional responses, and perceived product value. Use this data to iterate product development and marketing efforts to better meet consumer

expectations and strengthen brand positioning.

3) Collaborate with like-minded organizations, influencers, and community stakeholders to amplify brand visibility and credibility. Partnering with influencers who resonate with target audiences and collaborating with local communities on social initiatives can enhance brand authenticity and appeal. These partnerships can also provide opportunities for co-creating value and engaging consumers in meaningful ways that reinforce brand values.

By implementing these practical implications, social enterprises in Beijing can effectively enhance consumer satisfaction, stimulate repeat purchase intentions, and strengthen their market position as ethical and socially responsible brands. These strategies not only support business growth but also contribute to positive social impact and community engagement.

7. Limitation

While this study provides valuable insights into consumer behaviors towards social enterprise products in Beijing, several limitations should be considered. The findings, grounded in a specific cultural and geographical context, may not fully generalize to diverse consumer populations or other global regions. Subjectivity in measuring sensory satisfaction and cognitive stimulation poses a challenge, warranting future research to adopt more objective methodologies. Moreover, the study's sample characteristics and the evolving nature of consumer preferences over time suggest a need for longitudinal studies with larger and more diverse samples.

Future research could also benefit from exploring cross-cultural comparisons, employing neuroscientific approaches, and investigating the impact of technological advancements on consumer perceptions and behaviors towards social enterprise products. Conduct comparative studies across different cultural contexts to examine variations in consumer responses to sensory satisfaction, cognitive stimulation, and purchase intentions for social enterprise products. Utilize neuroscientific methods, such as neuroimaging or psychophysiological measures, to investigate the neural correlates of sensory experiences and cognitive processing in relation to consumer behaviors towards social enterprise products.

Reference

[1] Canestrino, R., Ćwiklicki, M., Magliocca, P., & Pawełek, B. 2020. Understanding social entrepreneurship: A cultural perspective in business research. Journal of Business Research, Volume 110, p. 132-143.

[2] Méndez-Picazo, M. T., Galindo-Martín, M. A., & Castaño-Martínez, M. S. 2021. Effects of sociocultural and economic factors on social entrepreneurship and sustainable development. Journal of Innovation & Knowledge, Volume 6 No. 2, p. 69-77.

[3] Hoang, D., Kousi, S., Martinez, L. F., & Kumar, S. 2023. Revisiting a model of customer engagement cycle: a systematic review. The Service Industries Journal, Volume 43 No. 9-10, p. 579-617.

[4] Kumar, B., & Dholakia, N. 2022. Firms enabling responsible consumption: a netnographic approach. Marketing Intelligence & Planning, Volume 40 No. 3, p. 289-309.

[5] Shou, S., & Li, Y. 2024. Exploring the collaborative innovation operational model of government-industry-education synergy: a case study of BYD in China. Asian Journal of Technology Innovation, p. 1-36.

[6] Weisz, E., & Cikara, M. 2021. Strategic regulation of empathy. Trends in Cognitive Sciences, Volume 25 No. 3, p. 213-227.

[7] Prasad, A. A., & Kumar, R. S. 2022. Challenges and opportunities of brand corporate social responsibility classification: A review, new

conceptualization and future research agenda. International Journal of Consumer Studies, Volume 46 No. 6, p. 2071-2103.
[8] Hermawan, E., & Vikaliana, R. 2023. Does customer loyalty meet repurchase and purchase intention?. Inovator, Volume 12 No. 2, p. 197-212.
[9] Shahid, S., Paul, J., Gilal, F. G., & Ansari, S. 2022. The role of sensory marketing and brand experience in building emotional attachment and brand loyalty in luxury retail stores. Psychology & Marketing, Volume 39 No. 7, p. 1398-1412.
[10] Williams, P., Escalas, J. E., & Morningstar, A. 2022. Conceptualizing brand purpose and considering its implications for consumer eudaimonic well-being. Journal of Consumer Psychology, Volume 32 No. 4, p. 699-723.
[11] Kaur, H., & Rana, A. 2022. From pure aesthetics to sensory gratification: Shifting Paradigm of aesthetic pleasure in Indian popular campus fiction. International Journal of English and Comparative Literary Studies, Volume 3 No. 3, p. 13-28.
[12] Ross, S. M., & Milne, G. R. 2021. Price? Quality? Or sustainability? Segmenting by disposition toward self-other tradeoffs predicts consumers' sustainable decision-making. Journal of Business Ethics, Volume 172, p. 361-378.
[13] Bernarto, I., Berlianto, M. P., Meilani, Y. F. C. P., Masman, R. R., & Suryawan, I. N. 2020. The influence of brand awareness, brand image, and brand trust on brand loyalty. Jurnal Manajemen, Volume 24 No. 3, p. 412-426.
[14] Gupta, P., & Srivastava, R. 2024. Research on social enterprises from an emerging economy—Systematic literature review and future research directions. Journal of Social Entrepreneurship, Volume 15 No. 2, p. 458-493.
[15] Choi, E. J. 2021. Why are products of social enterprises not purchased continuously? A re-purchase model for social enterprises. Global Business & Finance Review (GBFR), Volume 26 No. 3, p. 33-50.
[16] Mandagi, D. W., Rampen, D. C., Soewignyo, T. I., & Walean, R. H. 2024. Empirical nexus of hospital brand gestalt, patient satisfaction and revisit intention. International Journal of Pharmaceutical and Healthcare Marketing, Volume 18 No. 2, p. 215-236.
[17] Herrmann, A., Heitmann, M., Morgan, R., Henneberg, S. C., & Landwehr, J. 2009. Consumer decision making and variety of offerings: The effect of attribute alignability. Psychology & Marketing, Volume 26 No. 4, p. 333-358.
[18] Pullman, M. E., & Gross, M. A. 2004. Ability of experience design elements to elicit emotions and loyalty behaviors. Decision Sciences, Volume 35 No. 3, p. 551-578.
[19] Geva, A., & Goldman, A. 1991. Duality in consumer post-purchase attitude. Journal of Economic Psychology, Volume 12 No. 1, p. 141-164.
[20] Lim, S. H., & Kim, D. J. 2020. Does emotional intelligence of online shoppers affect their shopping behavior? From a cognitive-affective-conative framework perspective. International Journal of Human–Computer Interaction, Volume 36 No. 14, p. 1304-1313.
[21] Zhang, J. Z., & Chang, C. W. 2021. Consumer dynamics: Theories, methods, and emerging directions. Journal of the Academy of Marketing Science, Volume 49, p. 166-196.

Marketing Strategy Affecting the Decision to Purchase Decathlon's Products

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Abstract

The research objectives are to find the marketing strategies of Decathlon in China and study marketing strategies affecting the decision to purchase Decathlon's product. This paper selects Decathlon as the research subject to explore ways to improve customers' decision-making processes when purchasing Decathlon products. This research employs a mixed-method approach. The qualitative research utilizes online resources and conducts in-depth interviews with experts, customers, and professionals. Additionally, the researcher also used the quantitative research by designing a questionnaire focused on customer decision processes and 4Ps marketing strategies. The researchers used the multiple regression linear to analyze the data. From the result, the interviewees mentioned that price and location are the most important factors when they chose to buy the products from the Decathlon. Based on the statistical analysis, result indicates that 75.5% of the variance in the dependent variable (Decision to Purchase) is explained by the independent variables (Product, Price, Place, and Promotion). Moreover, from the summary of the effect of marketing mix on decision to purchase Decathlon's product, the researchers have found that among these predictors, Promotion has the largest standardized coefficient (β = 0.866). The standardized coefficient (β) is 0.098, indicating a positive relationship between Price and decision to purchase. Moreover, the researchers found that place has a positive relationship with decision to purchase (β = 0.134). The researchers have found that the product doesn't influence the decision to purchase based on the result. The research can make a conclusion that the price, place and promotion have a positive influence on the decision to purchase of Decathlon's products.

Keywords: Marketing Strategy, Decision to Purchase, Decathlon

1. Introduction

Nowadays, the development of China's sports industry is very important, which is related to the realization of building a moderately prosperous society in an all-round way and basically realizing the goal of socialist modernization. In addition, the "Healthy China 2030" strategy once again sounded the clarion call for the development of the fitness and leisure industry. It is of great significance to promote national fitness and sports consumption and to promote the high-quality development of sports industry. Mass sports plays an important role in various policy documents concerning sports and health in China. This drives the enthusiasm of the whole people to participate in sports, and then drives the sales of sports goods [1].

With the improvement of economic level, people pay more and more attention to their health, fitness has become a part of people's life, people actively participate in a variety of sports projects, the corresponding increase in the demand for sports goods, sports goods market ushered in a golden period of development.

In this context, this paper will take Decathlon as the research object. Decathlon is a company that mainly sells sports products with a wide variety of products and detailed classification. Facing the mass sports market, Decathlon mainly provides cost-effective products for sports users. Products are divided into low -, middle - and high-order facing different consumer groups. As of July 31, 2019, Decathlon has 294 stores in China, covering about 112 cities across the country. Store speed is very fast, its products by the vast number of consumers love. Decathlon's success in China is inseparable from its unique marketing model[2].

Decathlon's marketing strategy today, while clear and useful, faces challenges. (1) The cost-effective strategy adopted by Decathlon. The strategy of many companies will use the low price strategy, and the low price strategy is often the key factor that can impress the nerves of consumers. These strategies are well known, the key to the problem is to integrate this complete set of strategies, clearly communicate to consumers, pay attention to the word clarity, the most taboo in business is to advocate not clear enough, what kind of consumer groups are you facing? Can you bring value to them? Is the fundamental reason for the development of the company. (2) Decathlon almost does not do advertising, and its publicity costs are strictly controlled within 1% of the turnover. Word-of-mouth marketing and experiential marketing are its main marketing methods. Otherwise, all marketing means should be closely followed under the framework of marketing strategy. (3) The most important two points in Decathlon's marketing: one is word-of-mouth marketing, and the other is deep experiential marketing. Word-of-mouth marketing is easy to understand. It is to maximize the value perception of customers with good product quality and high cost performance, so as to recommend it to people around you. The information you hear from people you know is often more persuasive than TV advertisements. The most ideal state of word of mouth is that good word of mouth can be passed from you to the people around you and then to all mankind, of course, this possibility is very small [3].

This paper mainly studies the specific marketing strategies of Decathlon in China, promotes its good business model to local sports goods enterprises, and puts forward suggestions on expanding the development of local sports goods sales industry.

2. Literature review

McCarthy proposed the 4P combination for the first time in 1960. His book Basic Marketing describes in detail that the 4P combination specifically includes four elements: Product, Price, Place and Promotion. Since these four words start with P, they are shortened to "4P's [4].

2.1 Concepts of Marketing Mix

Marketing first branched out from economics. The acceleration of industrialization accelerated the development of marketing. At the beginning of the 20th century, a more specific marketing theory system was gradually formed. "Marketing mix", which mainly refers to the rational distribution of various factors such as product packaging, promotion, advertising and personnel to realize profit maximization[5]. For the first time, Jerome McCarthy summarized the elements of enterprise marketing as the specific implementation of Product, Price, Place and Promotion plans to promote the completion of transactions and achieve the goals of individuals and organizations, which is the famous 4P theory in history. The essence is that internal factors and external environment can better adapt to some specific methods and measures.

Michael Rose studies customer marketing and points out that customer marketing plays

an important role in marketing strategies. Customer marketing is a group organization as a whole, so as to carry out strategic marketing. With the popularization of big data in daily life, customer marketing may be transformed into inter-enterprise marketing in the future [6]. Christian Homburg analyzed the management of customer experience marketing and believed that such specific experience mode can increase the stickiness between enterprises and customers if it is applied to actual operations [7]. These specific marketing theories have played a certain role in promoting the development of marketing history and solved a series of problems in the specific marketing process of enterprises.

The research on marketing in China has also experienced a long development. With the booming development of China's economy, many experts and scholars have studied marketing theories and put forward a large number of different opinions and views. Effectively promote the development of Chinese marketing theory. In addition, Chinese scholars refer to the research results of many foreign scholars in their research, and then combine with China's national conditions and actual conditions to improve and innovate. Some scholars take different brand marketing under the "O2O" model as the research object, and believe that with the popularization of mobile Internet technology, online marketing will bring huge sales volume to enterprises. Therefore, enterprises can effectively combine online and offline marketing, and consumers can experience offline and then buy online. Truly realize the O2O development model (Zhang, 2019). Some scholars say that, taking the experiential marketing of clothing brand terminal stores as the research object, they believe that enterprises must think from the perspective of customers when they really promote experiential marketing. Only after customers have a good experience of products can they have the desire to buy, so as to promote product sales and finally achieve corporate profits. Of course, it still exists. The research on the marketing effect of online brand community on brand draws the conclusion that online brand community is an inherent advantage in the development of enterprises. Enterprises must build multi-platform community system as much as possible to build sustainable brand relations.

2.1.1 Decathlon's Products

At present, Decathlon company belongs to the sporting goods retail industry with the largest variety of sporting goods. Decathlon's products are classified according to sports, there are nearly 40 sports products, corresponding to more than 80 kinds of products. Each sport is equipped with the corresponding equipment and matching plan. For example, in the sport of badminton, when a junior badminton player wants to play badminton with friends on the weekend, but does not know how to choose the equipment to play badminton, Decathlon provides you with a complete solution. From the need to wear sports clothes, hats, sports shoes and sports equipment can be provided for you. Consumers only need to find the types of badminton sports in the Decathlon official flagship store, and then the corresponding is the gender attribute of consumers, and then you can find the corresponding clothing, footwear, sports functional equipment and other sporting goods. Clear product categories can help customers complete shopping quickly.

2.1.2 Decathlon's Price

Price strategy refers to the enterprise through the evaluation of customer demand and cost analysis, and finally choose a strategy to attract customers and realize the marketing mix[8]. Marketing objective and cost are the core of enterprise pricing. The clearer the enterprise is about its objective, the easier it is to set the price. However, cost determines the lower limit of product price. Different market types should have different pricing. For example, in a perfectly competitive

market, the price of a product is mainly determined by the supply and demand relationship in the market, and enterprises can only passively accept it. In this case, enterprises do not need to spend much time on marketing strategies.

2.1.3 Decathlon's Place

Channel strategy is an important part of the whole marketing system, mainly divided into direct channel and indirect channel two types. It can also be divided into online sales and offline sales, as well as the new retail sales models that have emerged in recent years[9]. The effective formulation of channel strategy is of great significance to reduce the cost of enterprises and improve the competitiveness of enterprises.

2.1.4 Decathlon's Promotion

Promotion strategy is one of the basic strategies of marketing mix. It refers to how enterprises pass product information to consumers or users through personal sales promotion, advertising, public relations and business promotion, so as to arouse their attention and interest, stimulate their purchase desire and behavior, so as to achieve the purpose of expanding sales [10].

2.2 Decision to purchase

There are five stages in the purchasing decision process: problem identification, information collection, program evaluation, purchasing decision and post-purchase behavior.

The purchasing decision made by the customer is the process in which the customer makes the purchase and choice of a certain product or brand service through careful evaluation. In a broad sense, this kind of purchase decision is to meet the specific needs of consumers. At the same time, when the purchase motivation is reached, consumers make the best choice of two purchase plans by means of analysis and evaluation, and can carry out follow-up evaluation of product purchase. This activity process consists of several steps, which are demand identification and formation of purchase motivation, making purchase decision and post-purchase evaluation.

The intensity of motivation, the amount of information at the earliest stage, and the difficulty of obtaining information will all have an impact on information collection, and information can be transmitted to consumers from different channels. As shown in the figure below, personal sources, commercial sources and public sources are all communication channels of information, and different sources will bring different influences to product buyers[11]. On the whole, consumers can rely on this commercial source to get more product information, but personal source is the most effective way of information sources, while commercial information sources have their own limitations, that is, they can only inform consumers about product information, and personal information sources are actually consumers' evaluation of products.

2.3 Related theories

Customer marketing is a group of organizations as a whole, so as to carry out strategic marketing. With the popularization of big data in life, customer marketing will likely be transformed into marketing between enterprises in the future.

Customer experience marketing management can be applied to actual operations, and this specific experience model can increase the adhesion between enterprises and customers [12]. These specific marketing theories have played a certain role in promoting the development of marketing history, and have solved a series of problems in the specific marketing process of enterprises.

Sales of sporting goods should start from the actual needs of customers and pay attention to the application of experience marketing in actual sales, so as to better promote the sales of sporting goods.

Current marketing strategy of sporting goods should adopt a variety of promotional means to strengthen the interaction between

enterprises and customers in the marketing process. Sponsorship of urban sports events can increase the brand image of sporting goods in the eyes of consumers and improve brand loyalty [13]. The marketing of sporting goods should be positioned accurately to enhance the brand awareness of the product.

American sporting goods as the research object, analyzed them with the 4P theory, and concluded that experiential marketing is based on consumers' demand for sporting goods, and rich marketing means can better promote product sales.

At present, all walks of life pay more and more attention to marketing, and more and more research on sporting goods marketing, but the research on Decathlon is still quite limited, but you choose a very unique and innovative Angle. Decathlon's competitive strategy from the perspective of competitive strategy.

The ability of enterprise leaders and marketing personnel to comprehend the market environment directly affects the long-term development of enterprises. Italian scholars conducted horizontal and vertical comparative studies on several enterprises from a macro perspective, striving to explore the different effects of the formulation of the same marketing strategy among different enterprises and the same effects achieved by different enterprises using different marketing strategies.

Thus, the researchers proposed the hypothesis as below:

（1）Product affects the decision to purchase Decathlon’s products.

（2）Price affects the decision to purchase Decathlon’s products.

（3）Place affects the decision to purchase Decathlon’s products.

（4）Promotion affects the decision to purchase Decathlon’s products.

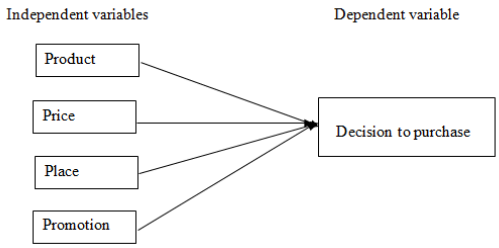

Fig 1: Marketing Mix conceptual framework

3. Methodology

This paper chooses Decathlon as the research object, to research how to improve customer’s decision-making process in purchasing decathlon’s products. This research is mixed method research.

What’s more, to base on 4P or any other marketing theories, this paper analyzes Decathlon's marketing strategy, obtains the existing problems in Decathlon's marketing strategy, and finally puts forward specific innovative optimization measures in combination with Decathlon's actual development.

3.1 Qualitative study

We take Decathlon’s customers, professionals and experts from this industry as interviewees to conduct the investigation. Through interviews with them who study sports industry and sports economy about sports industry and Decathlon brand, to obtain some valuable views for this study.

The sample size in each group:

1. Decathlon customer group: 3 persons. They are customers who purchase decathlon products and also other brands products with a subjective attitude.
2. Internal professional group: 3 persons. They are the marketing employees from Decathlon in China (2 person) and the headquarter (1 person) who know well about Decathlon brand.
3. External expert group: 3 persons. They are outside sports workers in marketing area with sufficient market knowledge and experience in Chinese sports equipment industry.

3.2 Quantitative study

The researcher will design a

questionnaire about 4Ps, customer decision process and marketing strategy. What's more, the answer of each question will be marked as notes 1, 2, 3, 4, 5 to facilitate the calculation process.

The researcher will collect all questionnaire through online and offline and use a statistics program to calculate and analyze the answers.

Validity and reliability of research instruments

(1) Validity

The content validation was carried out by three experts, Index of the Item Objective Congruence (IOC) was computed for the survey questionnaire. Index of Item Objective Congruence (IOC) [14] points of congruence were rated. IOC scores reached the high level of value 0.95 and The IOC points in calculations provided into three scales of rating for consistency and congruencies of the items. All experts had to choose only one answer as the given mark from these three alternatives of choices:

+1: If experts definite feeling that an item is a measure of an objective.

0: If experts undecided about whether the item is a measure of an objective.

-1: If experts definite feeling that an item is not a measure of an objective.

Total points for each item must have the consistency value equal to or above 0.50 [14].

The formula for calculating the IOC= Σ R/N

Where: IOC=Item Objective Congruence

R= Sum of the scores of individual experts

Σ R Total scores from each experts

N= Number of experts

It was also examined by 3 experts for the IOC analysis which ranges from +1 to -1. The total marks of each item from all experts produced out different outcomes. However, the idea to examine the IOC regarding consistency as validity must not lower than 0.50.

The panel of experts

Expert 1 - Pornladda Dathratwibul, Chief Executive Officer Genie Service Company Limited and Genie Insurance (Thailand) Public Company Limited

Expert 2 - Nuanphan Kaewpanukrangsi, Phd., Lecturer of 3D-Based Communication Design & Integrated Media, Faculty of Architecture, King Mongkut's Institute of Technology Ladkrabang

Expert 3 - Mongkol Tiamtanom, Lecturer of Marketing, Faculty of Management Science, Dhonburi Rajabhat University

(4) Reliability

After IOC approval was obtained, the researcher conducted sample of 30 participants from one group is similar to the sample. The researcher uses the Cornbrash's alpha (α) formula to reliability of the 30 questionnaires (Table 3.1).

Cornbrash's alpha (α) formula: α =Nc/(v+(N-1)c)

Where: N=the number of items

c=average covariance between item-pairs

v=average variance

The questionnaire items with Cornbrash's alpha 0.70 or greater than 0.70 were used as 0.70 is acceptable according to Cornbrash's alpha rating scale.

Table 1 Rating Scale

Cornbarash's alpha	Internal consistency
α≥0.9	Excellent
0.9>α≥0.8	Good
0.8>α≥0.7	Acceptable
0.7>α≥0.6	Questionable
0.6>α≥0.5	Poor
α≥0.5	Unacceptable

For this research questionnaire the validity test revealed that the average score of each item had consistency value (IOC≥0.50) and the reliability test revealed that the value of α was 0.7 or above. This suggested that the validity and reliability of this questionnaire was at an acceptable level as the following table.

Table 2: The Result of Item Objective Congruence (IOC) and Reliability Testing

Variable	Number of Question	Questions	IOC	Cronbach's Alpha
Product	4	Q1-Q4	1,1,0.67, 1	0.870
Price	4	Q5-Q8	1, 0.67, 1, 0.67	0.903
Place	4	Q9-Q12	1,1,0.67,1	0.908
Promotion	5	Q13-Q16	1,1,1,1	0.845
Decision to Purchase	4	Q17-Q20	0.67,1,1,1	0.868

Use a statistics data analysis method such as descriptive statistics, mean, S.D were used in this study. Moreover, multiple regression also used to analyze the respondents' answer. The quantitative research method means the data process of questionnaire results. We mark the options of the questions as different notes and use a statistical program to analyze the results.

Because the 4Ps on customer decision to purchase in Decathlon is the primary subject of this research. The researchers would like to use the descriptive analysis of mean to know each demographic information. Practical descriptive analyses are supported by a range of empirical approaches. The most common descriptive tools are basic statistics that capture fundamental patterns and variance, which may be very helpful for interpreting data. The descriptive researcher must distill the body of information into a format that the audience will find useful. This data reduction does not mandate that a circumstance or phenomena be given the same weight across all of its constituent parts. Instead, it focuses on the most important elements of the phenomena as it already exists as well as, more broadly, the context of real-world practice in which a research report is to be interpreted. Descriptive analysis can help us to know much details about the respondents, such as gender, age, income, education status. Thus, setting up the descriptive analysis is necessary for us to know all the related information.

Besides, the variables will also use the descriptive analysis. Based on the calculation, we can find that add the totals and divide that number by the total number of respondents to get the sentiment score. According to the sentiment score, we can find that respondents who are interested into which selection and understand that which selection that the users' preference.

Besides, we also used the inferential analysis to make sure the hypothesis can be supported. When the p-value is less than 5 percentage which means we can support the hypothesis. It is possible to utilize regression analysis to precisely identify the variables affecting a particular topic of interest. When you do a regression, you may safely determine which components are most crucial, which ones can be disregarded, and how these components interact.

4. Research results

Part 1 Qualitative research

The researcher has presented results of data analysis and interpretation for the purpose of this research in order to study the opinions of key informants in relating to find the marketing strategies of Decathlon in China. The research results have been divided into four parts which are: (1) Product Strategy (2) Price Strategy (3) Place

Strategy and (4) Promotion Strategy as per following details.

4.1.1 Product Strategy

In terms of the existing product types of Decathlon, more than 80 kinds of sporting goods, covering almost all sports and consumer age groups, 22, whether it is popular running, basketball, football, etc., or riding shoes, hunting equipment, snow and ice sports sets that are quite rare in other sporting goods sales companies. Even children's outdoor sports clothing and equipment are available; Not only has its own brands, such as the main team sports Kipsta, racquet Artengo, fitness Doymos, as well as foreign brands, such as Asics. Wang said Decathlon is one of his favorite brand because he can trust the product's quality and it is good for him to purchase the products again as he used to like buying Decathlon's products.

The respondents of Yang who said that Decathlon should take product quality as the starting point, Decathlon's online mall (including the official website and mall on Tmall) and its physical stores have both the main low-priced products and the high-end products specially provided by foreign manufacturers to meet the professional needs, such as the high-end running shoes of Asics. However, compared with the similar products sold in other places, their prices are still relatively low. Indeed, it is worth mentioning the successful marketing of the concept of "first price product".

4.1.2 Price Strategy

When Decathlon first entered the Chinese market in 2003, it was already a global chain sports distributor with considerable market share and reputation. Through penetration pricing, Decathlon's main products were much cheaper than those of domestic brands under the premise of quality assurance. The adoption of penetration pricing strategy, that is, to set a low price at the initial stage of the product entering the market, in order to quickly open the market and penetrate the market in the short term, so as to quickly attract as many consumers as possible, the purpose is to sacrifice the high gross profit in the short term to obtain a large number of market sales and share. The primary sports consumer goods market is a price-sensitive market with high price elasticity of demand. Under such a price strategy, Decathlon not only moves to a familiar development model, but also enhances the market competitiveness of its products. In 2009, Decathlon had 1,500 employees in China. The number of stores of Decathlon in China has reached 33, and the initial market layout has been completed.

Some of respondents have given suggestions as follows: *Zhang said that primary consumers are often attracted by the low price of Decathlon products, while most consumers usually set the price ceiling according to the judgment of product value.*

4.1.3 Place Strategy

Only in terms of the company's own products, Decathlon itself is both a manufacturer, but also a developer and retailer, because of its own production and sales, there is no agency, wholesale and other problems. If the products of other manufacturers in Decathlon supermarket are concerned, Decathlon's role will become a wholesaler or agent, because the proportion is too small, so we will not discuss it for the time being.

As a sports product retail enterprise integrating research and development, design, production and sales, Decathlon has a firm control over the entire product supply. Decathlon has been engaged in the production of products since 1986, and began its own brand classification in 1996. In the Chinese market, benefiting from a wide range of labor resources and low labor prices, Decathlon ensures that there will be no shortage of production capacity by opening foundries. After the products leave the factory in the different production centers, they are transported to Decathlon

supermarkets in various cities through reliable logistics management. In this way, Decathlon's role as producer and manager in the upstream channel has been completed. The advantage of this is to ensure product quality from the source and reduce the cost of finding product distribution channels. Some of respondents have given suggestions as follows: *Li answered that in terms of retail terminals, Decathlon builds Decathlon Sports Supermarket by leasing a large area of land, which ensures a wide area and convenient transportation in site selection.*

4.1.4 Promotion Strategy

Decathlon's target consumer group has been mentioned above, that is, it is mainly the general public, covering all sports types and consumers of all ages. This group of people is often very sensitive to price and belongs to the primary sporting goods consumers. From the online and offline aspects, Decathlon offline shopping malls mainly target residents around the location of the shopping mall and residents who expand to other locations in the city through transportation lines, while online electronic shopping malls have no obvious distinction. For a company that wants long-term benefits, simply using traditional promotional means to spread products to the mall is not enough, so for such consumers, Decathlon not only from the commodity price publicity, but also launched a variety of promotional tactics.

The first is Decathlon's experiential marketing. At Decathlon, when customers enter the sports supermarket, they can easily find specialized trial products around the shelves. Both indoor and outdoor experience areas of Decathlon can provide trial venues for customers. Such experiential marketing, completely across the unfamiliar gap between products and consumers, better than all kinds of advertising and promotional slogans. Some of respondents have given suggestions as follows: *Wang said that promotion strategy was launched by Decathlon to provide consumers with perfect product services and improve consumer loyalty.*

Part 2 Quantitative Research

4.2.1 Basic Information of the respondents

Table 3: Basic Information of the respondents

(n=358)

Item	Category	Population	Percentage（%）
Gender	Male	187	52.2
	Female	171	47.8
Age	Under 18	53	14.8
	18-25	129	36
	25-35	91	25.4
	more than 35	85	23.7
Family Income	Under 2500RMB	53	14.8
	2500-6000RMB	128	35.8
	6000-10000RMB	86	24
	More than 10000RMB	91	25.4
Education Background	Under college	69	19.3
	Bachelor	134	37.4
	Master or above	155	43.3
Habitat	Urban	157	56.1
	Rural	201	43.9

(1) From the perspective of gender, among the samples of this survey, 171 were female, accounting for 47.8%, and 187 were male, accounting for 52.2%. The ratio of the two was almost 1:1, and the ratio between men and women was relatively balanced, so the samples were relatively representative.

(2) According to the age composition, there were 53 samples aged 18 years and 18 years and above, with a percentage of 14.8%. There were 129 samples ranging in age from 18 to 25, representing 36% of the total sample. Among the 25-35 age group, 91 samples were included in the sample, accounting for 25.4% of the total sample. The total number of participants in the 85 people aged 35 and older was 23.7%. Consistent with the age profile of the customer.

(3) In terms of educational attainment, only 69 people were from secondary schools and above, representing a rate of 19.3%. Among them, there were 134 samples with bachelor's degree or above, accounting for 37.4%. With 155 students as subjects, 43.3% of the survey subjects were subjects. A total of 36 master's and doctoral students were collected in this study, and the sample coverage rate was 10.1%. This construction suggests that the sample users are more educated at a college level.

(4) In terms of family economic status, there are 53 samples in the sample of 2500 yuan and above, and 14.8% of the sample. Among the samples between 2500 and 6000 yuan, 128 samples were sampled, and 35.8% of the samples were sampled. Among samples of 6000 to 10000 yuan, the percentage of 86 samples is 24%, and the percentage of 91 samples is 25.4%.
(5) The number of people living in the city is the largest, with 201 people, accounting for 56.1%.

4.2.2 Opinion on marketing mix and decision to purchase

Table 4: Opinion on Overview Variables

(n=358)

Overview of Variables	Mean	Standard deviation	Interpret	Ranking
Product	3.57	.736	the lowest	5
Price	4.00	.738	low	2
Place	4.03	.699	high	1
Promotion	3.80	.660	neutral	4
Decision to Purchase	3.89	.825	the highest	3
Total	3.86	.732		

From the overview of variables, the researchers have found that place has the highest mean value which is 4.03 in this study. Then, there are price, decision to purchase, promotion, and product which are 4.00, 3.89, 3.80, 3.57 respectively.

Variables	Mean	Standard Deviation	Min	Max	CV	Skewness	Kurtosis
Product	3.57	.736	1	5	.542	.045	-.111
Price	4.00	.738	1	5	.545	-.485	.377
Place	4.03	.699	1	5	.489	-.215	-.152
Promotion	3.80	.660	1	5	.436	-.130	.267
Decision to purchase	3.89	.707	1	5	.499	-.210	.025

Product has the lowest mean value in this study which is 3.57. The standard deviation of the product is .736. The skewness value is .045 and Kurtosis is -.111.
Price has the high mean value in this study which is 4.00. The standard deviation of the price is .738. The skewness value is -.485 and Kurtosis is .377.
Place has the highest mean value in this study which is 4.03. The standard deviation of the place is .699. The skewness value is -.215 and Kurtosis is -.152.
Promotion has the high mean value in this study which is 3.80. The standard deviation of the promotion is .660. The skewness value is -.130 and Kurtosis is .267.
Decision to purchase has the high mean value in this study which is 3.89. The standard deviation of the decision to purchase is .707. The skewness value is -.210 and Kurtosis is .025.

Table 5: Results of correlation analysis of variables

	product	price	place	promotion	Decision to purchase
Product	1				
Price	.470**	1			
Place	.458**	.576**	1		
Promotion	.483**	.623**	.669**	1	
Decision to purchase	.453**	.584**	.525**	.861**	1

From the table, we would like to use Pearson correlation to analyze the data and we find that all the variables are significant due to the p-value less than 5 percentage. What's more, we find that decision to make and promotion has a very high correlation. However, each independent variable is good and have a medium correlation between the 0.4 and 0.6. Thus, all the independent variables are fine to use in this study.

Table 6: Results of multiple regression analysis of variables

Variables	R^2	a constant	b	Std. Error	β	t	p	VIF	Tolerance
Product	.755	.368	.049	.028	.051	1.717	.087	1.421	.704
Price			.093	.032	.098	2.887	.004	1.842	.543
Place			.135	.036	.134	-3.810	.000	2.004	.499
Promotion			.927	.040	.866	23.409	.000	2.208	.453

From the table, we can find that the promotion has the most influential (β value is .866), followed by place has a secondary influence (β =.134) and the product has the least influential (β =.051) on the decision to purchase Decathlon's products. The R square is .755 which means when the promotion, product, price and place increased, decision to purchase will also increase about 75.5%. We have found that VIF is in the range of 1 to 5 which means there is a slight possibility that the variables may have correlation between each other. Collinearity is fine in this study.

Table 7: The result of the hypothesis testing

Hypothesis	Level of significance	Result
H1: The product has a positive influence on decision to purchase in Decathlon's store	.087	Reject H1
H2: The price has a positive influence on decision to purchase in Decathlon's store	.004	Support H2
H3: The place has a positive influence on decision to purchase in Decathlon's store	.000	Support H3
H4: The promotion has a positive influence on decision to purchase in Decathlon's store	.000	Support H4

We also found that product is more than 5 percentage which means we need to reject the result of product on decision to purchase. Moreover, we found that price, place, and promotion have influence on the decision to purchase due to the p-value less than 5 percentage which are .004, .000, .000 respectively.

5. Conclusions

First of all, low price and high quality is a concept that has been established since the establishment of Decathlon, and it is also one of the magic weapons that has continued to operate. As the researcher found that price strategy has a positive influence on decision to purchase in Decathlon's store. Therefore, Decathlon should continue to take this concept as its production mission to reduce product costs as much as possible while ensuring product quality. Only after customers have a good experience of products can they have the desire to buy, so as to promote product sales and finally achieve corporate profits [15]. Place strategy has a positive influence on decision to purchase in Decathlon's store. In addition to providing cost-effective products, but also to continue to introduce new products, and make it adapt to the needs of the market, so as to be in an invincible position in the incentive market competition[16]. Promotion strategy has a positive influence on decision to purchase in Decathlon's store. The current marketing strategy of sporting goods should adopt a variety of promotional means to strengthen the interaction between enterprises and customers in the marketing process [17].

In addition, to increase the physical store customer experience satisfaction, improve after-sales service. Customer marketing of price, product, place, and promotion play an important role in marketing strategies to their customers' purchase decision. One of the characteristics of Decathlon's business is that customers can experience all the products in the mall, which is the so-called experiential marketing. Therefore, Even if the physical store operating costs are high, this experience model still needs to be maintained, and will be maintained. The improvement of people's living standards, ordinary experience can no longer be complete.

Moreover, to meet the needs of customers, the ultimate experience is the goal of customers. Therefore, Decathlon must continue to innovate the experience model, not only limited to simple product trial experience, but also should introduce some additional innovative experience, in order to better attract customers to form customer-brand relationship [18]. Price is important for their customers as a proper price of the product would attract more customers and help them to make a decision to purchase the products. Finally, the existing after-sales service of Decathlon also needs to be improved. Decathlon should continue to pay a return visit to the large sports equipment sold to understand the feelings of customers in the use process at any time. In the actual operation, we must make every customer shopping is very satisfied, because only the customer is satisfied. It is possible to make customers buy twice and increase customers' trust in Decathlon.

Acknowledgement

I am sincerely thanks for my advisor Dr. Lalita Puangmaha. They have helped me a lot during this study. Without their guidance and help, I can't finish this individual research and they taught me a lot.

Reference

[1] X. Wei, J. Zhang, O. Lyulyov, and T. Pimonenko, "The role of digital economy in enhancing the sports industry to attain sustainable development," *Sustainability*, vol. 15, no. 15, p. 12009, 2023.

[2] K. Voss, I. K. Rizaoglu, A. Balcerzak, and H. Hansen, "Solar energy engineering and solar system integration–The solar Decathlon Europe 21/22 student competition experiences," *Energy Build.*, vol. 285, p. 112891, 2023.

[3] R. Pavlović, M. Vrcić, and B. Petrović, "Athletic decathlon: are there differences between the results of decathlon recordholders and their best personal results," *J. Phys. Educ. Res.*, vol. 7, no. 2, pp. 18–26, 2020.

[4] G. K. Hunter and W. D. Perreault Jr, "Making sales technology effective," *J. Mark.*, vol. 71, no. 1, pp. 16–34, 2007.

[5] W. O'Neil, "Hypothetical terms and relations in psychological theorizing," *Br. J. Psychol.*, vol. 44, no. 3, p. 211, 1953.

[6] G. Dominici, "From marketing mix to e-marketing mix: a literature overview and classification," *Int. J. Bus. Manag.*, vol. 4, no. 9, pp. 17–24, 2009.

[7] N. H. Borden, "The concept of the marketing mix," *J. Advert. Res.*, vol. 4, no. 2, pp. 2–7, 1964.

[8] C. L. Goi, "A review of marketing mix: 4Ps or more," *Int. J. Mark. Stud.*, vol. 1, no. 1, pp. 2–15, 2009.

[9] M. T. Nuseir and H. Madanat, "4Ps: A strategy to secure customers' loyalty via customer satisfaction," *Int. J. Mark. Stud.*, vol. 7, no. 4, p. 78, 2015.

[10] M. Zineldin and S. Philipson, "Kotler and Borden are not dead: myth of relationship marketing and truth of the 4Ps," *J. Consum. Mark.*, vol. 24, no. 4, pp. 229–241, 2007.

[11] N. M. Chauhan, "Consumer behaviour and his decision of purchase," *Int. J. Res. Manag. Pharm.*, vol. 2, no. 5, pp. 1–4, 2013.

[12] N. Barber and B. A. Almanza, "Influence of wine packaging on consumers' decision to purchase," *J. Foodserv. Bus. Res.*, vol. 9, no. 4, pp. 83–98, 2007.

[13] R. Dhiman, P. K. Chand, and S. Gupta, "Behavioural aspects influencing decision to purchase apparels amongst young Indian consumers," *FIIB Bus. Rev.*, vol. 7, no. 3, pp. 188–200, 2018.

[14] R. K. Hambleton and L. L. Cook, "Latent trait models and their use in the analysis of educational test data," *J. Educ. Meas.*, pp. 75–96, 1977.

[15] R. Karim, N. A. Latip, A. Marzuki, S. Haider, M. Nelofar, and F. Muhammad, "The impact of 4ps marketing mix in tourism development in the mountain areas: A case study," *Int. J. Econ. Bus. Adm.*, vol. 9, no. 2, pp. 231–245, 2021.

[16] Z. Xia, N. Li, and X. Xu, "A Bibliometric Review of Analyzing the Intellectual Structure of the Knowledge Based on AI Chatbot Application from 2005–2022," *J. Inf. Syst. Eng. Manag.*, 2023.

[17] N. Niazi, M. Rashid, and Z. Shamugia, "Role of marketing mix (4ps) in building brand equity: Case study of Shell Petrol, UK," *Int. J. Appl. Bus. Manag. Stud.*, vol. 6, no. 1, p. 2021, 2021.

[18] Z. Xia and R. Shannon, "CONCEPTUALIZING AI-CHATBOT APPLICATION AS AN E-SERVICE AGENT TO DEVELOP A CUSTOMER-BRAND RELATIONSHIP," *Oper. Res. Eng. Sci. Theory Appl.*, vol. 7, no. 1, 2024.

Marketing Strategies to Increase Competitive Advantages for Nanning Tobacco Company

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Abstract

This paper aims to study the current marketing strategies of Nanning Tobacco Company, analyze the existing issues, and propose optimization suggestions. The research employs qualitative methods, including literature review and in-depth interviews.The literature review surveys and analyzes theories and research on tobacco marketing globally and domestically. The in-depth interviews target marketing managers from Nanning Tobacco Company, tobacco shop owners, and cigarette consumers , covering five aspects: product, price, place, promotion, and social enterprise strategy.The study finds that Nanning Tobacco Company faces several issues, including a lack of brand diversity in product promotion, price opacity, insufficiently detailed channel terminal layout, a lack of innovation in promotions, and insufficient information transparency in social enterprise strategies.To enhance the competitive advantage of Nanning Tobacco Company, the paper proposes the following suggestions: diversify the tobacco product line, adhere to unified pricing, optimize terminal layout, increase innovation in promotions, improve information transparency in social enterprise strategies, and explore cross-industry collaborations.

Keywords: Nanning Tobacco Company, Marketing Strategy, Competitive Advantage

Introduction

China is not only the world's largest tobacco producer, but also the world's largest tobacco consumer. According to statistics, China's tobacco cigarette production in 2021 is about 2.4 trillion sticks, and the total number of smokers reaches 300 million people.However, with the tightening of international and domestic tobacco control compliance, the tobacco marketing environment will continue to "deteriorate"; and the emergence of various types of new e-cigarette products will also differentiate a large number of inherent cigarette consumer groups, cigarette consumer groups will be gradually reduced, so the future of cigarette marketing work to continue to improve and enhance the future sales of cigarettes will have an important impact, and the focus lies in the enhancement and optimization of cigarette marketing strategy. (Wang, 2022)

Guangxi Zhuang Autonomous Region, at the connection point between China and Southeast Asian countries, has geopolitical importance, and in 2022, China's provinces ranked 16th in the country in terms of cigarette production, with 71.814 billion cigarettes produced, which belongs to the key tobacco-producing provinces, and

Nanning, as the capital of China's Guangxi Zhuang Autonomous Region, will play a unique role in the circulation of tobacco products between China's domestic market and Southeast Asia.

Under such a background, this paper takes Nanning Tobacco Company as an example, analyzes the problems existing in the current marketing strategy of Nanning Tobacco Company, and how to enhance its competitive advantages, and optimizes its marketing strategy.Finally, as a unique industry, from a social enterprise perspective, how can it promote the survival and long term development of the tobacco industry, and how can it fulfill its social enterprise obligations in promoting the building of a harmonious society.

Conceptual Framework

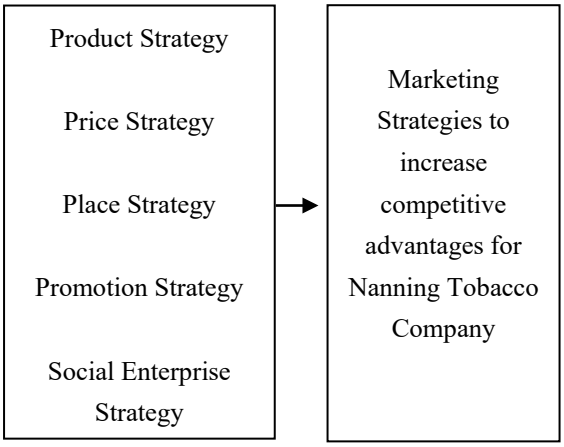

Figure 1.1 Conceptual framework

Research Objectives

1. To study product strategy of Nanning Tobacco Company
2. To study the price strategy of Nanning Tobacco Company
3. To study the place strategy of Nanning Tobacco Company
4. To study the promotion strategy of Nanning Tobacco Company
5. To study the social enterprise strategy of Nanning Tobacco Company

Literature Review

Concepts of Cigarette Marketing

Cigarettes refer to tobacco products commonly known as "cigarettes," excluding cigars.Cigarette marketing is through the service, the cigarette consumer groups to maintain their own around, through all kinds of promotions, tangible display to attract the cigarette consumer groups, attention to their needs, through the product mix and new products to meet the process of their cigarette products consumption experience.

Theory of 4Ps Marketing

The 4Ps emerged with the introduction of marketing mix theory. Jerome McCarthy, a professor at the University of Michigan in the United States (Jerome McCarthy) in 1960 in his "basic marketing" (BasicMarketing) in a book will be these elements are generally summarized in four categories: product (Product), price (Price), place (Place), promotion (Promotion) known as the 4Ps.

Theory of Social Enterprise

Social Enterprise (SE) is a form of organization that combines business goals and social mission to solve social problems through business means. Social Entrepreneurs are the founders of these organizations, driven by innovation and change to achieve social value through business (Dees, 1998). At the heart of social enterprises lies their dual mission: to achieve financial sustainability and to create positive social impact (Alter, 2007).

Research methodology

This is a qualitative method study, including literature research and in-depth interviews, with the main focus on a

comprehensive analysis of Nanning Tobacco Company's marketing strategy in five areas: product, price, place, promotion and social enterprise.

The data for this study came from three sets of in-depth interviews, which focused on collecting information from 25 in-depth interviewees, including 5 marketing executives from Nanning Tobacco Company, 10 Nanning Tobacco Shop owners, and 10 consumers of cigarettes.

Nanning Tobacco Company marketing executives: mainly in certain management positions in the company, with more than 5 years of experience;

Nanning Tobacco Shop Owner: Tobacco store experience of at least 3 years in Nanning;

Cigarette Consumers: Smoke for more than 3 years and spend more than 1500 RMB/month on cigarettes.

Results

1. Product Strategy of Nanning Tobacco Company

By synthesizing and analyzing the interview results and research data, the following conclusions can be drawn about Nanning Tobacco Company's product strategy:

1. The current product strategy is too focused on the "True Dragon" brand, resulting in a lack of market diversification. The company should consider enriching its product line and introducing more competitive brands to meet the needs of different consumers.

2. The lack of flexibility in the current product placement strategy, the company should adjust the principle of stock placement and increase the freedom of retail customers to purchase goods.

3. Enhancement of supply chain management,ensure the stability and timeliness of product supply.

4. Strengthen brand promotion and marketing,understand the needs of different consumer groups, to develop targeted brand promotion and marketing strategies to enhance brand awareness and market influence.

2. Price Strategy of Nanning Tobacco Company

By synthesizing and analyzing the interview results and research data, the following conclusions can be drawn about Nanning Tobacco Company's pricing strategy:

1. Maintaining the strategy of unified national pricing: The strategy of unified national pricing has played an important role in maintaining market stability and brand imag

2. Improve price transparency: Through the establishment of a perfect price supervision mechanism, to protect the rights and interests of consumers and enhance the consumer's purchasing experience.

3. Management of consumer price sensitivity: the company needs to pay attention to changes in market demand and reasonably adjust its pricing strategy to ensure that it does not affect consumers' willingness to buy when prices fluctuate.

3.Place Strategy of Nanning Tobacco Company

By synthesizing and analyzing the interview results and research data, the following conclusions can be drawn about Nanning Tobacco Company's channel strategy:

1. The current terminal channel layout is relatively sloppy, and more precise

planning is needed according to market demand and consumer behavior. Especially in high-traffic areas, we need to avoid the phenomenon that tobacco stores are too dense.

2. In the face of fierce market competition and the problem of some non-compliant tobacco stores, the Company needs to strengthen its supervision of retail stores. Timely closure of non-compliant stores optimizes the market environment and improves overall sales performance.

4. Multi-channel sales strategy: Combined with consumers' purchasing preferences, the company can explore a multi-channel sales strategy. In addition to traditional offline channels, actively expand online sales channels to provide consumers with more convenient purchasing options.

5. Utilizing new media and technological means:Channel management and consumer interaction through digital means enhances the connection between brands and consumers and improves market responsiveness.

4.Promotion Strategy of Nanning Tobacco Company

By synthesizing and analyzing the interview results and research data, the following conclusions can be drawn about Nanning Tobacco Company's promotional strategy:

1. Current promotional activities are too single and lack innovation. The company should increase the variety and creativity of promotional activities

2. Utilizing new media platforms for promotion: The company should make full use of these platforms to publicize brand promotion and promotional activities through social media and online advertising. At the same time, internal employees and retail customers are encouraged to participate in new media promotions to create a multi-channel publicity effect.

3. Explore cross-border marketing cooperation: The company should actively explore opportunities for cooperation with other brands, such as joint promotions with liquor and specialty brands and launching combination packages.

4. Implementing personalized and customized promotions: Personalized promotions can not only increase sales, but also enhance customer brand loyalty.

5.Social Enterprise Strategy of Nanning Tobacco Company

By synthesizing and analyzing the interview results and research data, the following conclusions can be drawn about Nanning Tobacco Company's social enterprise strategy:

1. Enhancing information transparency: Publish social responsibility reports on a regular basis, showing in detail the company's specific initiatives and achievements in social welfare, environmental protection and technological innovation. Through social media and official websites and other platforms, update relevant information in real time, so that the public can better understand and recognize the company's social contributions.

2. Explore cross-border cooperation: At present, the company's business scalability in terms of social enterprise strategy is insufficient, and in the future it can consider cross-border cooperation with other industries.

3. Enhanced support for retailers and consumers: Regular training is organized for retailers to enhance their business capacity and service level. At the same time, consumer health education activities are

carried out to promote the concept of healthy smoking and enhance consumers' brand loyalty.

4. Enhancing environmental protection and technological innovation.

Discussions

1. Product strategy

In examining the product strategy, this study finds that the company's product strategy focuses mainly on promoting the local brand "True Dragon". Although this strategy has improved the brand's market recognition and sales performance to a certain extent, it has also revealed some obvious problems,. In this paper, we will discuss these problems from several perspectives and explore their implications for the future development of Nanning Tobacco Company in the light of relevant literature.

1. The biggest problem associated with centralized brand promotion is the lack of market diversification. As noted in the literature, centralized branding can lead to an over-reliance on a single brand and the neglect of other potential market opportunities (Keller, 2013).

2. Currently, Nanning Tobacco Company's product placement strategy is relatively rigid, and retail customers are limited to a fixed slot when purchasing goods, making it difficult to flexibly adjust inventory according to market demand. Literature shows that flexible supply chain management can significantly improve the market responsiveness and customer satisfaction of companies (Christopher, 2016)

3. Consumer loyalty to brands is also an important aspect that Nanning Tobacco Company needs to focus on. Research has shown that consumers are more loyal to cigarette brands and that brands are the primary consideration in their purchasing decisions (Schiffman & Kanuk, 2007).

4. The plight of shopkeepers further highlights the inadequacy of the product strategy. Although the True Dragon brand performed well in the market, there were significant problems with availability. Often, store owners were unable to flexibly adjust their inventory to meet market demand, especially during peak selling seasons, when they were unable to obtain sufficient supplies, resulting in lost sales opportunities.

2. Price strategy

In studying the pricing strategy , this study found that its pricing strategy adopts national uniform pricing. However, in practice, there are problems of unauthorized price adjustment by some retailers. This paper will discuss these problems from several aspects and explore their impact on the future development of Nanning Tobacco Company in the light of relevant literature.

1. The national uniform pricing strategy plays an important role in maintaining market stability and brand image.

2. Consumers are less sensitive to price and pay more attention to brand and taste. Research has shown that brand and product quality play a key role in consumers' purchasing decisions, while price is only a secondary factor (Zeithaml, 1988).

3. Lack of transparency in price management is also an issue of concern.

3. Place Strategy

The findings of Nanning Tobacco Company in terms of channel strategy show that the company has obvious deficiencies and challenges in terminal layout, service quality, channel competition and

multi-channel sales strategy. This paper will discuss these issues in these aspects and explore their impact on the future development of Nanning Tobacco Company in the light of relevant literature.

1. The importance of terminal channel layout. Nanning Tobacco Company's terminal layout is currently based on the distance factor as the main consideration, and the layout is relatively sloppy, resulting in insufficiently precise channel coverage. This problem has also been mentioned in the literature, and optimizing terminal layout can significantly improve sales effectiveness and customer satisfaction (Berman & Evans, 2018) .

2. The improvement of service quality is a key issue in the channel strategy. Retail service quality has a direct impact on consumers' purchasing experience, and studies have shown that improving service quality can effectively increase customer satisfaction and loyalty (Parasuraman, Zeithaml, & Berry, 1988).

3. The intensity of channel competition is the main challenge facing retail stores today. Especially in popular areas, the layout of tobacco stores is too dense, which not only increases the pressure on store owners to operate, but also leads to unsustainable business for some stores. Too much competition in the market may lead to price wars and deterioration of service quality, which is consistent with the literature (Porter, 1980).

4. Utilizing new media and technology tools for channel management and branding is an effective strategy to improve market responsiveness. Literature shows that digital means can effectively enhance the connection between brands and consumers and improve the market response rate (Chaffey & Ellis-Chadwick, 2019) .

4. Promotion strategy

Nanning Tobacco Company's promotional strategy revealed several key points in the interview findings and research conclusions, including the monolithic nature of existing promotions, the potential to leverage new media and digital platforms, the exploration of cross-border marketing, personalized and customized promotions, and consumer expectations of promotional activities. This paper will discuss these aspects of promotional strategies and explore their implications for the future development of Nanning Tobacco Company in the light of relevant literature.

1. The homogeneity of existing promotional activities is one of the main problems facing Nanning Tobacco Company. Research has shown that innovative promotional activities can significantly increase consumers' brand awareness and purchase intention (Shimp, 2010).

2. Utilizing new media and digital platforms for promotions is an effective means to enhance the effectiveness of promotions. studies have shown that digital means can effectively enhance the interaction between brands and consumers and improve market response (Armstrong & Kotler, 2015)

3. The exploration of cross-border marketing is another direction of interest. Crossover marketing can bring new market opportunities and a wider consumer base through cooperation with other brands. For example, joint promotions with alcohol or specialty brands can lead to combination packages that can both enhance brand image and attract more consumers (Aaker, 2011).

4. Personalized and customized promotion is also an effective strategy to enhance brand image and sales. Providing

customized tobacco products to large customers can meet the special needs of occasions such as corporate receptions and wedding events, which not only enhances the brand's premium image but also attracts specific consumer groups (Schiffman & Kanuk, 2007) Personalized and customized promotions can increase sales as well as enhance brand loyalty among customers. Studies have shown that personalized marketing can significantly increase customer satisfaction and brand loyalty (Solomon, 2018).

5. Social enterprise strategy

In examining the social enterprise strategy, this study finds that the company has significant shortcomings and challenges in the areas of social responsibility fulfillment, information transparency, business expansion, and support for retailers and consumers. This paper will discuss these issues in these areas and explore their implications for the future development of Nanning Tobacco Companyin the light of relevant literature.

1. The problem of insufficient information transparency limits the impact of the Nanning Tobacco Company's social enterprise strategy. Research has shown that information transparency is crucial to the effectiveness of CSR, and that transparent information enhances public trust and recognition of the company (Clarkson, 1995).

2. The limitation of business expansion is an important issue in Nanning Tobacco Company's social enterprise strategy. Currently, the company mainly focuses on the tobacco industry itself and lacks cross-border cooperation with other industries. Literature points out that cross-border cooperation can bring new market opportunities and social impact for companies (Austin, 2000).

3. Support for retailers and consumers is also an area where Nanning Tobacco Company needs to improve. Research has shown that companies can improve their overall business performance and social responsibility by enhancing their support to stakeholders (Freeman, 1984) .

4. Enhancing environmental protection and technological innovation is also an important part of Nanning Tobacco Company's social enterprise strategy. Research has shown that environmental protection and technological innovation can not only enhance the market competitiveness of enterprises, but also make positive contributions to society and the environment (Porter & van der Linde, 1995).

5. Establishing transparent and open communication mechanisms that enable retailers and consumers to participate more directly in a company's social enterprise strategy is key to enhancing a company's interaction and trust with the community.

Recommendations

1. Product Strategy Optimization Recommendations

The mission of cigarette products is to meet the consumption needs of cigarette consumer groups. The optimization of Nanning Tobacco Company's product strategy should be explored around the following points:

1. Adjustment of product specification mix: It should focus on the group needs of its own cigarette consumer market, and not overly concentrate on the provincial cigarette promotion and placement.

2. Enhanced matching of market demand: Tobacco companies should communicate with retail customers to understand the real market demand, according to the market demand to adjust the product placement, to ensure that the product supply to match the market demand, to avoid mismatch between supply and demand.

3. Combating counterfeit, smuggled and illicit cigarettes

2.Price Strategy Optimization Recommendations

As far as Nanning Tobacco Company is concerned, it has no independent pricing power over retail prices. Therefore, in terms of price strategy, it mainly focuses on the retail price to do a good job in the direction of price indication, strengthen supervision and management, and ultimately ensure the stability of the price.

1. Enforcement of clear and unambiguous prices.

2. Establishment of Integrity Support Groups.

3. Strengthening market regulation.

3. Place Strategy Optimization Recommendations

1. Scientific layout of retail outlets: How to reasonably and hierarchically set the layout of retail terminals, in terms of density, distribution and structure of the precise force, is conducive to the creation of a stable and harmonious environment of the cigarette market.

2. Collect and update retail customer information in a timely manner: In order to better serve the needs of retail customers, effectively rectify and standardize the order of the cigarette market in Nanning City, collect and update the information of retail customers in a timely manner, conduct sampling surveys for different types of retail customers in different industries, different regions, and do not use the type of retailer customer information to comprehensively analyze the current market supply and demand situation.

3. Increased sensitization and training of retail customers: Carry out planned, systematic and focused thematic training for retail customers to enhance their business management capabilities.

4. Promotion Strategy Optimization Recommendations

Under the strict regulations of the new advertising law, the restrictions on cigarette promotion are getting stricter and stricter. Promotional activities are carried out in accordance with the formulation of promotional plans and innovative promotional methods, which are mainly categorized into two types of promotional methods for retail customers and consumers.

For retail customers

New media promotion: Avoiding the restrictions of venue and time, allowing more retail customers to participate, and realizing the brand radiation of "point to point".

Cross-border combination marketing promotion: Cooperate with liquor or specialty stores and other places to build special counters and zones for "specialty + cigarettes" and "liquor + cigarettes", forming certain package combinations and promoting each other's final sales.

Consumer-oriented Experiential marketing: Combine with the heat distribution range of competing business districts to precisely locate the consumption areas that match the

purchasing preference of the cigarette brand, combine with the construction of new modern terminals, select the terminals with a good store environment and strong customer management ability as experience stores, and make joint efforts to create sample rooms with brand elements。

Personalized customization promotion: customized printing of pictures, text, logos, etc. on cigarette packaging for cigarette consumers, giving cigarette products more social and humanistic features and functional attributes, used in wedding celebrations, reunions, birthday parties, chambers of commerce, annual meetings of enterprises, commemorations of events, private customization, business openings and advertising and publicity scenarios.

5. Recommendations for optimizing social enterprise strategies

The following more detailed optimization suggestions are proposed for Nanning Tobacco Company's social enterprise strategy to enhance its social enterprise strategy, improve its competitive advantage and achieve sustainable development.

1. Enhance information disclosure and transparency.

2. Actively expand business and industrial cooperation: Nanning Tobacco Company should actively expand its business scope and carry out cross-border cooperation with new energy and environmental protection industries.

3. Continuing to increase investment in poverty alleviation and education.

Recommendations for Future Research

1. In-depth study of the impact of different product strategies on market performance:Although this study suggests optimization of Nanning Tobacco Company's product strategy, it has not yet fully explored the specific impact of different product strategies on market performance. Future research can compare the effects of different product strategies such as brand expansion, diversified product lines and customized products on consumer purchasing behavior and market share through empirical analysis. This will help the company to formulate its product strategy more precisely.

2. Assessing the long-term effectiveness of place strategies

This study puts forward suggestions to optimize terminal layout and strengthen service quality, but there has not been a quantitative assessment of their long-term effects. Future research can track the implementation effects of different channel strategies over time by establishing a channel performance evaluation model to assess their impact on market coverage, customer satisfaction and sales.

3. Research on the application and effectiveness of innovative promotional strategies

This study suggests that Nanning Tobacco Company increase the diversity and innovativeness of its promotional activities, but it has not yet conducted a systematic study on the effects of specific promotional tools. In the future, experimental design and data analysis can be used to help the company choose the most effective promotional strategies.

4. Overall assessment and improvement of social enterprise strategies

This study points out that Nanning Tobacco Company has deficiencies in information transparency and business expansion in terms of social enterprise strategy, and future research can assess in

depth the company's actual performance in fulfilling its social responsibility.

Further research in these directions can provide Nanning Tobacco Company with more comprehensive and in-depth strategic recommendations to help it continue to improve its competitive advantage and realize sustainable development in the competitive market environment.

REFERENCES

[1] Wang Ting. (2022). Comparison Analysis of Cigarette Production Volume, Tobacco Label Market Size, and Key Companies: Dongfeng Corporation vs Jingjia Corporation in China in 2021.

[2] Dees, J. G. (1998). The meaning of social entrepreneurship. Kauffman Foundation.

[3] Alter, K. (2007). Social enterprise typology. Virtue Ventures LLC.

[4] Keller, K. L. (2013). Strategic brand management: Building, measuring, and managing brand equity (4th ed.). Pearson.

[5] Christopher, M. (2016). Logistics & supply chain management (5th ed.). Pearson.

[6] Schiffman, L. G., & Kanuk, L. L. (2007). Consumer behavior (9th ed.). Pearson Prentice Hall.

[7] Zeithaml, V. A. (1988). Consumer perceptions of price, quality, and value: A means-end model and synthesis of evidence. *Journal of Marketing, 52*(3), 2-22.

[8] Berman, B., & Evans, J. R. (2018). Retail management: A strategic approach (13th ed.). Pearson.

[9] Parasuraman, A., Zeithaml, V. A., & Berry, L. L. (1988). SERVQUAL: A multiple-item scale for measuring consumer perceptions of service quality. *Journal of Retailing, 64*(1), 12-40.

[10] Porter, M. E. (1980). Competitive strategy: Techniques for analyzing industries and competitors. Free Press.

[11] Chaffey, D., & Ellis-Chadwick, F. (2019). Digital marketing: Strategy, implementation, and practice (7th ed.). Pearson.

[12] Shimp, T. A. (2010). Advertising, promotion, and other aspects of integrated marketing communications (8th ed.). South-Western College Pub.

[13] Armstrong, G., & Kotler, P. (2015). Marketing: An introduction (12th ed.). Pearson.

[14] Aaker, D. A. (2011). Brand relevance: Making competitors irrelevant. Jossey-Bass.

[15] Solomon, M. R. (2018). Consumer behavior: Buying, having, and being (12th ed.). Pearson.

[16] Clarkson, M. B. E. (1995). A stakeholder framework for analyzing and evaluating corporate social performance. *Academy of Management Review, 20*(1), 92-117.

[17] Austin, J. E. (2000). The collaboration challenge: How nonprofits and businesses succeed through strategic alliances. Jossey-Bass.

[18] Freeman, R. E. (1984). Strategic management: A stakeholder approach. Pitman.

[19] Porter, M. E., & van der Linde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives, 9*(4), 97-118.

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