Rina Fitriana

Developing a food safety model for biogenic silica powder from palm oil boiler ash using soft system methodology

Teknik Industri

Document Details

Submission ID

trn:oid:::3618:133483799

Submission Date

Mar 30, 2026, 9:27 AM GMT+7

Download Date

Mar 30, 2026, 9:48 AM GMT+7

File Name

bioconf_icfse2026_02003.pdf

File Size

2.6 MB

13 Pages

4,133 Words

24,011 Characters

4% Overall Similarity

The combined total of all matches, including overlapping sources, for each database.

Filtered from the Report

- Bibliography
- Quoted Text
- Small Matches (less than 10 words)

Exclusions

- 40 Excluded Sources
- 2 Excluded Matches

Match Groups

12 Not Cited or Quoted 4%
Matches with neither in-text citation nor quotation marks

0 Missing Quotations 0%
Matches that are still very similar to source material

0 Missing Citation 0%
Matches that have quotation marks, but no in-text citation

0 Cited and Quoted 0%
Matches with in-text citation present, but no quotation marks

Top Sources

1% Internet sources
2% Publications
2% Submitted works (Student Papers)

Integrity Flags

0 Integrity Flags for Review

Our system's algorithms look deeply at a document for any inconsistencies that would set it apart from a normal submission. If we notice something strange, we flag it for you to review.

A Flag is not necessarily an indicator of a problem. However, we'd recommend you focus your attention there for further review.

Match Groups

- **12** Not Cited or Quoted 4%
  Matches with neither in-text citation nor quotation marks
- **0** Missing Quotations 0%
  Matches that are still very similar to source material
- **0** Missing Citation 0%
  Matches that have quotation marks, but no in-text citation
- **0** Cited and Quoted 0%
  Matches with in-text citation present, but no quotation marks

Top Sources

1% Internet sources
2% Publications
2% Submitted works (Student Papers)

Top Sources

The sources with the highest number of matches within the submission. Overlapping sources will not be displayed.

1	Student papers	University of Central England in Birmingham on 2013-03-21	<1%
2	Publication	Chinaza Godswill Awuchi. "HACCP, quality, and food safety management in food ...	<1%
3	Publication	Jai Verma, Meletios Bimpizas-Pinis, Amos Ncube, Sven Kevin van Langen et al. "In...	<1%
4	Publication	H S S Perangin-angin, A D Ritonga, I Fauzan, H Thamrin. "Policy impact analysis of...	<1%
5	Internet	www.researchgate.net	<1%
6	Internet	educationdocbox.com	<1%
7	Student papers	Athabasca University on 2002-07-26	<1%
8	Publication	Pradyut Anand, Surya Dev Singh, Priyam Nath Bhowmik, Veeresh Boya, Shatrudh...	<1%
9	Publication	Mohamad Yusak Anshori, Puspandam Katias, Teguh Herlambang, Nur Shabrina ...	<1%
10	Student papers	Universitas Indraprasta PGRI on 2025-01-15	<1%

11 Internet

foodindustryhub.com **<1%**

BIO Web of Conferences **219**, 02003 (2026) https://doi.org/10.1051/bioconf/202621902003
ICFSE 2025

Developing a food safety model for biogenic silica powder from palm oil boiler ash using soft system methodology

Anni Rohimah[1,3], *Dadang* Surjasa[1*], *Rina* Fitriana[1], *Engelin* Shintadewi Julian[2], *Aton* Yulianto[4], and *Hoerudin*[4]

[1]Industrial Engineering, Universitas Trisakti, West Jakarta, 11440, Indonesia
[2]Electrical Engineering, Universitas Trisakti, West Jakarta, 11440, Indonesia
[3]Industrial Engineering, Universitas Muhammadiyah A.R. Fachruddin, Tangerang, 15720, Indonesia
[4]The National Research and Innovation Agency, South Tangerang, Banten,15314, Indonesia

Abstract. Palm oil is a strategic commodity for Indonesia, accounting for approximately 42% of the global supply. The increase in palm oil production has led to a growing volume of waste, particularly palm oil boiler ash, which contains biogenic silica with potential economic value. This study aims to develop a Soft System Methodology (SSM)-based model for optimizing the production of biogenic silica powder from palm oil boiler ash as an adsorbent to improve food packaging quality. The research applied Soft Systems Methodology, supported by Rich Pictures, Input–Process–Output (IPO) modeling, and the CATWOE framework. A conceptual model integrating biogenic silica characteristics and food safety requirements was developed. The results show that SSM effectively describes the complexity of biogenic silica utilization systems. Rich Picture illustrates relationships among waste sources, production processes, quality testing, risk assessment, and environmental impacts. The IPO model clarifies the transformation of inputs into value-added adsorbent products. The conceptual food safety model includes biogenic silica characteristics (porosity, moisture content, and SiO_2 content) and food safety parameters (microbiological, bacterial, and shelf-life testing). In conclusion, the proposed model supports systematic improvement through process standardization and raw material quality control, contributing to sustainable waste utilization and enhanced food packaging quality.

1 Introduction

4 According to data from the Palm Oil Plantation Fund Management Agency (BPDPKS), the palm oil industry generates approximately 60 million tons of waste, including liquid and solid

* Corresponding author: dadang@trisakti.ac.id

waste (palm powder). Every year, Indonesia is predicted to make more than 2 million tons of boiler ash from palm oil processing plants. Boiler ash is the waste from the combustion process of shell and fiber in the boilers of palm oil mills.. Agro-industrial waste can cause severe pollution if not properly managed. The bio-refinery concept can be applied to agro-industrial waste [1]. Sustainable techniques that can reduce environmental damage, produce valuable products from agricultural and food processing waste, and promote overall sustainability [2]. Agroindustrial waste has potential for energy and heavy metal remediation, e.g., bioadsorbents can effectively remove heavy metals from wastewater [3]. Agro-industrial wastes can be used for sustainable industrial processes. New technologies and applications are being developed to valorize agro-industrial waste [4].

5 Boiler ash is utilized as a partial replacement for sand in the production of concrete wall paving blocks. Production of biogenic silica from palm boiler ash can add value while reducing potential environmental risks **[5]**. Silica gel from palm kernel shell ash is effective as a moisture absorber for medicine bottle packaging **[6]**. For example, risk assessment held on cheese characteristics **[7]**.

This study aims to develop a Soft Systems Methodology (SSM)-based model to optimize the production of biogenic silica powder from palm oil boiler ash as an adsorbent to improve food packaging quality. The research applied Soft Systems Methodology, supported by Rich Pictures, Input–Process–Output (IPO) modeling, and CATWOE analysis, to capture system complexity, stakeholder interactions, and regulatory constraints.

2 Material And methods

Palm oil boiler ash is a waste product rich in silica (biogenic silica) and has the potential to be used as a raw material in the development of environmentally friendly adsorbents, particularly for food packaging applications. Palm oil boiler ash produced from the combustion of palm oil in the boiler unit of a palm oil mill is shown in Figure 1 below.

Fig. 1. Palm Oil Boiler Ash

Palm oil production data at one of the palm oil mills in Garut, West Java, is shown in Table 1 below.

Table 1. Palm oil production data

Data	December 2023	December 2024	July 2025
Fresh Fruit Bunch	28.704.600	29.102.130	14.068.140
Rendemen (%)	19,11	19,09	20,25

Stages to build a soft system methodology [8] to build the Conceptual Food Safety Model shown in Figure 2.

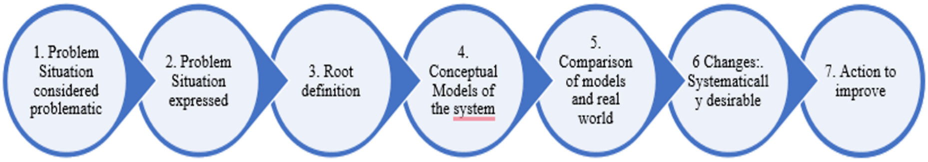

Fig 2. Soft system methodology stages for the food safety model

2.1 Problem exploration situation

This initial stage involves gathering information about the problem and drawing on literature, field observations, and interviews with the palm oil industry, food experts, and regulators to understand the context of palm oil boiler ash utilization and food packaging issues.

2.2 Create a "rich picture”

A visual representation of the problem situation highlights relationships, conflicts, and perspectives. To develop a comprehensive systemic model for the production and utilization of biogenic silica powder from palm oil boiler ash as an adsorbent in food packaging, this research uses one of the Soft System Methodologies, namely the Rich Picture. A Rich Picture is a holistic view of the system that includes process flow, stakeholders, elements, and interactions. A Rich Picture is a holistic view of the system, including the process flow, stakeholders, elements, and interrelationships between elements related to sustainability. It also discusses the environmental, social, and economic [9]. The rich picture is flexible across different types of research, such as build a traceability system for the rental equipment model, especially in the oil and gas industry [10]. This method is used to describe the complexity of the system in biogenic silica production, to describe interactions among stakeholders, and to map the linkages between sustainability and food safety. Steps to develop the Rich Picture are:

1) Identification of Stakeholders and Key Elements of the System
2) Material and Information Flow Tracing
3) Visual Representation in Rich Picture
4) Integration of Sustainability Elements
5) Conduct and Revise Rich Picture Diagram

The process of creating a rich picture is shown in the flowchart in Figure 3.

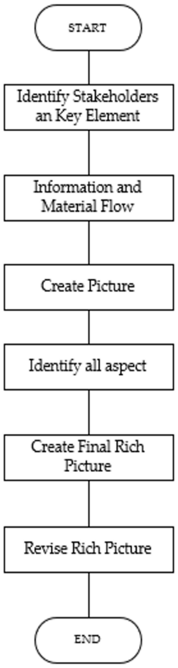

Fig. 3. Develop Rich Picture Stage

2.3 Root definition formulation (CATWOE analysis)

Identify and analyze Customer, Actor, Transformation, Weltanschauung, Owner, Environment to build the root definition of the ideal system.

2.4 Conceptual model creation

Following the rich picture, conceptual models are developed to represent the various systems and processes involved.

2.5 Comparison

The conceptual models are compared against the real-world situation, facilitating discussions among stakeholders to identify discrepancies and areas for improvement [11]. Comparing the model with the real situation to find gaps and potential interventions.

2.6 Identify feasible and desirable changes

Develop a list of changes that are systemically feasible, socially relevant, and acceptable to stakeholders.

2.7 Action

Action steps are formulated based on the insights gained, enabling iterative improvements to the system.

3 RESULT AND DISCUSSION

3.1 Problem exploration situation

Palm oil boiler ash has a high silica (SiO_2) content of 50-60%. From 20 tons of harvested oil palm fruit bunches per hectare, 154 kg of silica is produced. The silica produced by oil palm plants is called biogenic silica. Production of biogenic silica from palm boiler ash can add value while at the same time reducing potential environmental risks **[5]**. Palm oil production data are shown in Table 2.

Table 2. Palm oil production (2024)

Region	Palm oil production (ton)
Sukabumi	10617,17
Cianjur	3,32
Garut	26789,48
Tasikmalaya	67,81
Subang	1210
Pangandaran	239,63
Banjar	8,26

(source:jabarprov.go.id)

Palm oil boiler ash has been utilized in various applications across a range of industrial sectors and materials. This utilization demonstrates the potential of palm oil industrial waste as a value-added material that supports sustainability. A summary of the various forms of palm oil boiler ash utilization and the reporting year is presented in Table 3.

Table 3. Utilization of palm oil boiler ash

Utilization of palm oil boiler ash	Year
Partial replacement of sand in the manufacture of concrete	2021
Clay bath mix material	2015
Fertilizer for Ultisol soil	2010
Adsorbent for drug packaging	2015
Zeolite-based catalyst	2022
Geo Polymer Concrete reinforcement	2023
Improves chloride and sulfate resistance in mortar	2024

The relationship between input, process, and output in the development of a food safety model is shown in a diagram. This diagram shows how the characteristics of biogenic silica as input are analyzed through a series of adsorption and laboratory testing processes, resulting in a conceptual food safety model as the research output. The process diagram is shown in Figure 4.

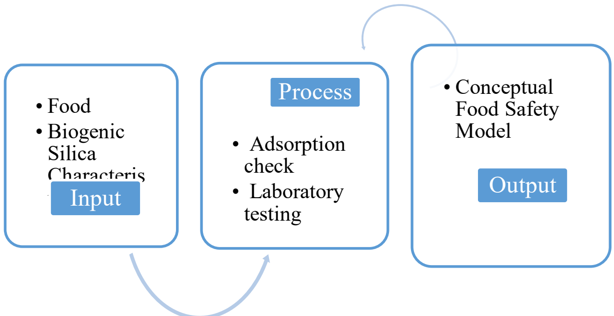

Fig. 4. Process Diagram (Input Process Output)

In the input stage, the study utilizes food ingredients and biogenic silica characteristics as initial variables. These characteristics are essential in determining the performance of biogenic silica as an adsorbent in food packaging. The process stage includes adsorption and laboratory testing to evaluate biogenic silica's interactions with specific components of the food system. The output stage produces a conceptual food safety model that summarizes the relationships among material properties, the adsorption process, and their implications for food safety. This model serves as an analytical framework for understanding the potential application of biogenic silica in food systems.

Results from the Focus Group Discussion with the National Research and Innovation Agency indicate that the characteristics of biogenic silica powder used as an adsorbent in food packaging were identified, namely: SiO_2 content, powder form, pore size, surface area, moisture content, and density. Modeling of cause-and-effect relationships between process and material variables. This modeling aims to understand system dynamics and reveal feedback mechanisms that influence the effectiveness of the adsorption process. These relationships are represented as causal loop diagrams in Figure 5.

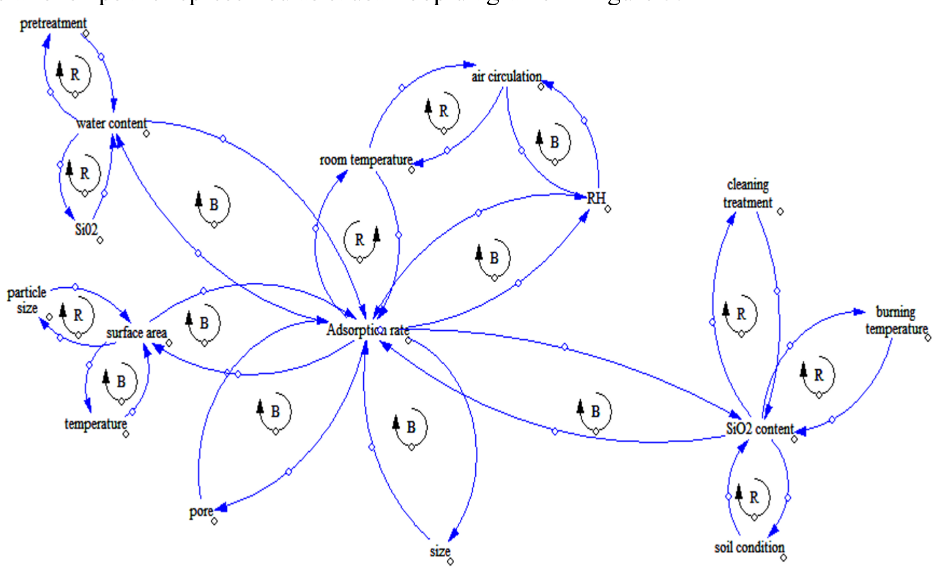

Fig. 5. Causal Loop Diagram

A Causal Loop Diagram (CLD) shows the relationship between physical, chemical, and environmental variables that affect the adsorption rate. CLD containing two loops, such as R (Reinforcing loop) and B (Balancing loop). The primary focus of the system shown in CLD is the adsorption rate. To describe the structure of the system analyzed in the causal loop diagram (CLD), the system is divided into several main subsystems based on material characteristics, environmental conditions, chemical composition, and manufacturing processes. This division aims to identify key variables that affect biogenic silica adsorption performance. Details of the subsystems and their constituent variables are presented in Table 4.

Table 4. Subsystem in CLD

Sub System	Content
Biogenic silica characteristic (adsorption rate)	Particle size, surface area, pore size, temperature, and moisture content
Environmental and storage conditions	Room temperature, RH, air circulation
Chemical composition	SiO_2 content, soil condition.
Manufacturing process	Burning temperature, cleaning treatment

The biogenic silica adsorption system comprises four main subsystems that interact with one another. The biogenic silica characteristic subsystem plays a dominant role because it includes physical variables such as particle size, surface area, pore size, temperature, and moisture content. The environmental and storage conditions subsystem, which provides for room temperature, relative humidity (RH), and air circulation, contributes to material stability and consistent adsorbent performance during storage and use. Variations in these conditions can alter the physical properties of biogenic silica, thereby affecting adsorption.
The chemical composition subsystem, particularly the SiO_2 content and soil conditions, determines the purity and chemical structure of the biogenic silica produced. This factor determines the quality of the initial material and influences the adsorbent-adsorbate interaction. The manufacturing process subsystem, which includes combustion temperature and cleaning treatment, plays a role in controlling pore structure formation and contaminant levels in biogenic silica. The interaction between these subsystems forms a feedback mechanism in CLD that, overall, determines the effectiveness of the adsorption process and its implications for food safety.

3.2 Create a "rich picture."

3.2.1 Sstakeholders and key elements of the system

Stakeholders involve communities producing boiler ash waste (palm oil mills), biogenic silica industry players, the food packaging sector, and end users. Include environmental (waste reduction, circularity), social (food safety testing), and economic (added value of waste products) aspects. Implementing a HACCP system involves the continuous application of record-keeping, monitoring, corrective actions, and all relevant activities outlined in the HACCP plan [12]. HACCP ensures food safety by determining critical control points and establishing preventive measures [[13]. LCA enables systematic evaluation of the environmental performance of potentially sustainable strategies, from raw materials to end-of-life products [14].

3.2.2 Visual representation in rich picture

Using visual symbols to describe processes, actors, and interactions between components. Added Life Cycle Assessment (LCA) flow and AI-based modeling for optimal production location determination to the subsequent research.

3.2.3 Integration of sustainability elements

This rich picture incorporates the three main pillars of sustainability: Environmental, Social, and Economic. It also includes a food-safety evaluation component to ensure that biogenic

silica is safe for use in food packaging. Integrating agricultural waste by-products offers a sustainable alternative by reducing waste and improving concrete properties [15].

3.2.4 Conduct and revise the rich picture diagram

The draft rich picture was validated through discussion with the participants. The Rich Picture Diagram is shown in Figure 6 below.

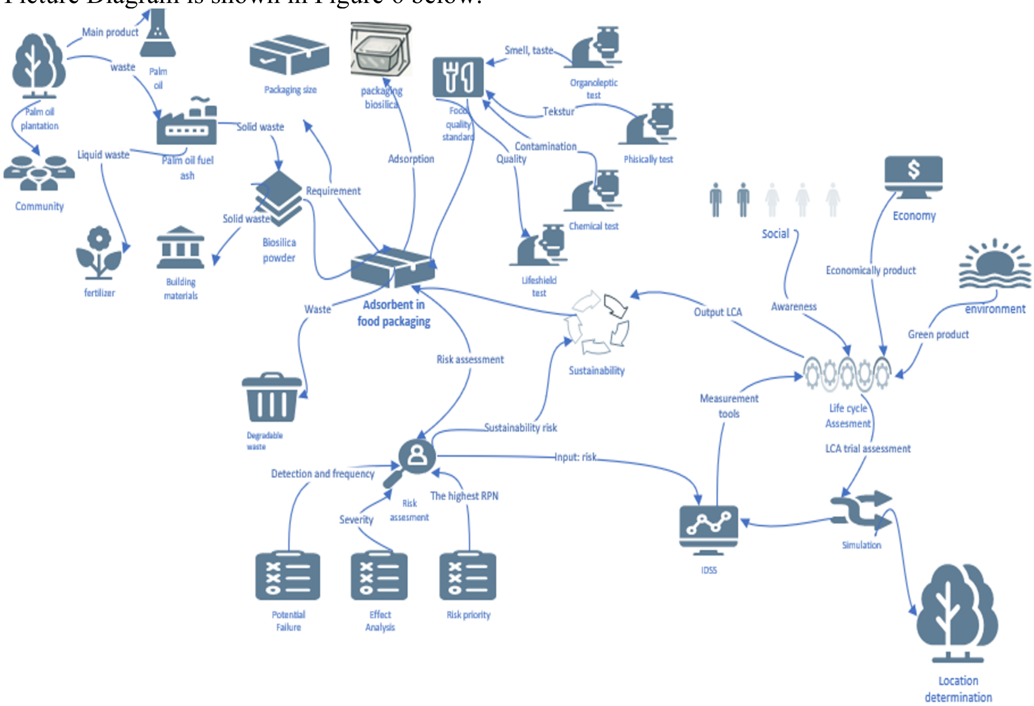

Fig. 6. Rich Picture Diagram

The description of the image above is as follows:
1. Value chain of biogenic silica that begins with raw materials, boiler ash from palm oil.
2. The extraction process into biogenic silica powder is held in laboratories.
3. Formulation into adsorbents for food packaging
4. Quality testing (SiO_2 content, porosity, moisture content)
5. Food safety testing (bacterial, microbiological)
6. Food life shield testing

3.3 Root definition formulation (CATWOE analysis)

To obtain information about the system under review, an analysis was conducted using the CATWOE framework. This analysis aimed to identify key stakeholders, transformation processes, and environmental contexts that influence the use of palm oil fuel ash as a biogenic silica source, food safety, and its application as an adsorbent. The results of the identification of each CATWOE element are presented in Table 5.

Table 5. CATWOE analysis

Customer	**Food Industry**
Actor	Researcher, palm oil plantation
Transformation	From palm oil fuel ash to biogenic silica, and then as an adsorbent
Weltanschauung	Utilizing agro-industrial waste into value-added products supports sustainable food production systems and the circular economy.
Owner	Palm oil processing companies, research institutions, local governments, and packaging business owners
Environment	Food safety regulations, environmental regulations, availability of waste, and technology

Customers (C)
Customers: The parties that receive the main benefits from this system are the food industry. The use of boiler ash waste as a biogenic silica adsorbent has the potential to produce food packaging with a longer, safer shelf life, while also opening new economic opportunities for the surrounding community.

Actors (A)
The leading actors in this system include researchers, producers of biogenic silica, and players in the food packaging industry. Their roles vary, ranging from technology development and implementation of production processes to food quality and safety testing and environmental impact assessment.

Transformation process (T)
The core transformation of the system is converting palm oil boiler ash waste into biogenic silica powder, which is then used as an adsorbent in food packaging, thereby improving food product quality and reducing environmental impact. This transformation process reflects the principles of the circular economy, in which industrial waste is processed into value-added products.

Worldview (W)
The worldview underlying this system is that using industrial waste as an alternative resource can create sustainable solutions for the food and environmental sectors. This system not only aims to address waste issues but also to increase economic value and public awareness of environmentally friendly products.

Owners (O)
The owners or decision makers in this system include palm oil processing companies, research institutions, local governments, and packaging business owners. They have the authority to allocate resources, make strategic decisions, and implement technology at laboratory or industrial scales.

Environmental constraints (E)
System constraints include food safety and environmental regulations, availability of waste raw materials, readiness of extraction and production technologies, and local socio-economic conditions and infrastructure.

3.4 Conceptual model creation

A framework was developed to integrate the characteristics of biogenic silica materials with food safety testing parameters to ensure their suitability and safety for application. A Conceptual framework for the protection of using biogenic silica as an adsorbent in food packaging is shown in Figure 7.

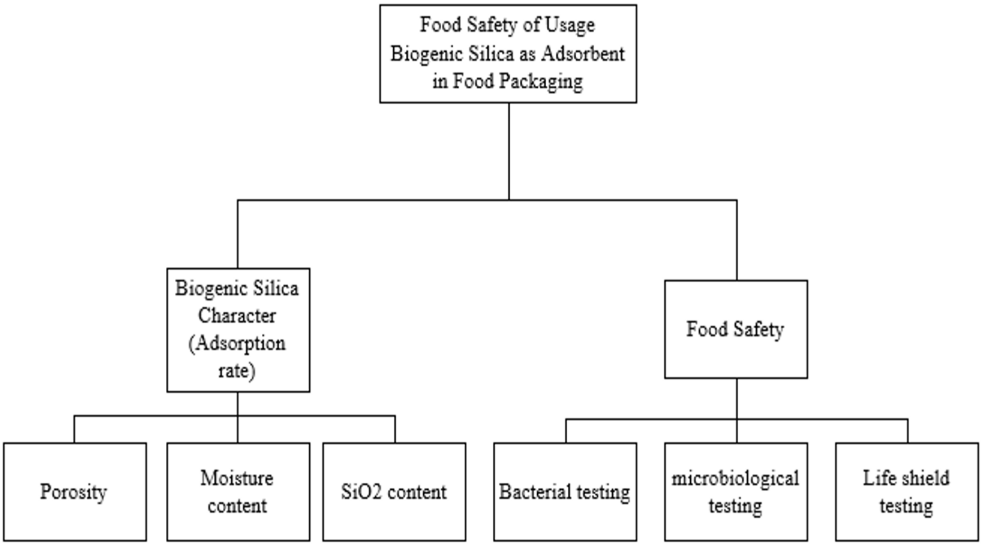

Figure 7. Conceptual food safety model of biogenic silica as an adsorbent in food packaging.

Conceptual methods indicate that the safety of using biogenic silica as an adsorbent in food packaging is determined by two main components: the characteristics of biogenic silica and food safety considerations. The attributes of biogenic silica include porosity, moisture content, and SiO_2 content. These parameters are essential for the effectiveness of biogenic silica in controlling the internal conditions of food packaging. Food safety aspects are evaluated through a series of tests, including bacterial, microbiological, and life shield tests. These tests aim to ensure that the use of biogenic silica does not pose a risk of microbial contamination.

3.5 Comparison

The conceptual models are compared against the real-world situation. Comparing the model with the real problem to find gaps and potential interventions. Comparison of the conceptual model and the real situation is shown in Table 6.

Table 6. Comparison of the conceptual model and the real situation

Conceptual Model (Ideal Condition)	**Real-World Condition**
Food safety is ensured through integrated characterization of biogenic silica and comprehensive food safety testing.	Studies and practices often separate material characterization from food safety assessment.
Adsorption performance is measurable, stable, and reproducible	Adsorption capacity varies between production batches

Controlled porosity optimized for moisture adsorption	Porosity is not precisely controlled.
Low and controlled moisture content	Moisture content fluctuates due to insufficient control over the drying process.
High and consistent SiO_2 content	SiO_2 content depends on the composition of palm boiler ash.
Comprehensive food safety evaluation before application	Food safety testing is often partial or limited.
Systematic testing for major pathogenic bacteria	Bacterial tests are not routinely conducted.
Complete microbiological analysis	Microbial testing is conducted selectively (TPC and *Salmonella*)
Shelf-life testing using active packaging systems	Shelf-life evaluation remains conventional.

3.6 *Identify feasible and desirable changes*

A list of changes that are systemically feasible, socially relevant, and acceptable to stakeholders is: raw material and process control, structural variability of pores, moisture management, and utilization of adsorbent functionality.

3.7 *Action*

Action steps are formulated based on insights gained, enabling iterative improvements to the system, such as process standardization and raw material quality control.

4 Conclusion

This study applied the Soft Systems Methodology (SSM) to analyze and design a system for utilizing palm oil boiler ash waste as a raw material for biogenic silica, an adsorbent for sustainable food packaging. Through the Rich Picture approach, the Input–Process–Output (IPO) model, and CATWOE analysis, a comprehensive understanding of the system was obtained, integrating technical, social, economic, and environmental aspects. The analysis results show that Rich Picture can identify process flows from the source of waste to environmentally friendly food packaging products, as well as the relationships between actors and stakeholders. The IPO model emphasizes the importance of integrating biogenic silica extraction processes and product characteristic testing. A CATWOE analysis helps clarify the role of each system component and the environmental and regulatory constraints that must be considered in actual implementation. A conceptual model supports systematic improvement through process standardization and raw material quality control, contributing to sustainable waste utilization and enhanced food packaging quality.

Acknowledgement. Thank you to the DPPM Ministry of Higher Education, Science, and Technology, which supports this research through the “Fundamental Regular Research Grant 2025” according to contract numbers 128/C3/DT.05.00/PL/2025, 1014/LL3/DT.06.01/2025, and 486/A/LPPM/USAKTI/VI/2025

References

1. E. Kasim, J. Stöhr, and C. Herzig, "Promoting sustainable palm oil in supply chain strategy: a food business case study," *Qual. Res. Organ. Manag. Int. J.*, vol. **16**, no. 3/4, pp. 550–571, Nov. (2021), doi: 10.1108/QROM-03-2020-1907.
2. L. Prasittisopin, "Power plant waste (fly ash, bottom ash, biomass ash) management for promoting circular economy in sustainable construction: emerging economy context," *Smart Sustain. Built Environ.*, Dec. (2024), doi: 10.1108/SASBE-09-2024-0395.
3. R. Singh, R. Das, and S. Sangwan, "Utilisation of agro-industrial waste for sustainable green production: a review," *Environ. Sustain.*, vol. **4**, no. 4, pp. 619–636, Dec. (2021), doi: 10.1007/s42398-021-00200-x.
4. D. Díaz-Vázquez, D. Carrillo-Nieves, D. A. Orozco-Nunnelly, C. Senés-Guerrero, and M. S. Gradilla-Hernández, "An Integrated Approach for the Assessment of Environmental Sustainability in Agro-Industrial Waste Management Practices: The Case of the Tequila Industry," *Front. Environ. Sci.*, vol. **9**, p. 682093, Jun. (2021), doi: 10.3389/fenvs.2021.682093.
5. Hoerudin, T. Hidayat, S. Yuliani, and K. Wahyuningsih, "Extraction yield and properties of biogenic silica from palm oil fuel ash: effect of re-ashing pretreatment and solvent concentration," *IOP Conf. Ser. Earth Environ. Sci.*, vol. **1354**, no. 1, p. 012012, Jun. (2024), doi: 10.1088/1755-1315/1354/1/012012.
6. L. Novita and I. Idris, "Effectiveness of silica gel from palm kernel shell ash as a moisture absorber of bottle packaging medicine," *IOP Conf. Ser. Earth Environ. Sci.*, vol. **1041**, no. 1, p. 012044, Jun. (2022), doi: 10.1088/1755-1315/1041/1/012044.
7. S. W. P. A. Lestari, E. H. Purnomo, and U. Hasanah, "Characterization on Safety Risks of Commercial Cheese in Indonesia," *Indones. Food Sci. Technol. J.*, vol. **7**, no. 2, pp. 141–147, Jul. (2024), doi: 10.22437/ifstj.v7i2.34033.
8. J. Warwick, "A Case Study Using Soft Systems Methodology in the Evolution of a Mathematics Module," *Math. Enthus.*, vol. **5**, no. 2–3, pp. 269–290, Jul. (2008), doi: 10.54870/1551-3440.1107.
9. K. P. Conte and S. Davidson, "Using a 'rich picture' to facilitate systems thinking in research coproduction," *Health Res. Policy Syst.*, vol. **18**, no. 1, p. 14, Dec. (2020), doi: 10.1186/s12961-019-0514-2.
10. A. E. Nurhidayat, R. Fitriana, D. Suhardini, and A. Nugrahanti, "The causal loop diagram model of traceability system rental equipment in oil and gas supporting companies," *TELKOMNIKA Telecommun. Comput. Electron. Control*, vol. **22**, no. 5, p. 1104, Jul. (2024), doi: 10.12928/telkomnika.v22i5.26084.
11. I. Phillips and C. R. Kenley, "An SSM-TRIZ Methodology for Business Problem Structuring," *INCOSE Int. Symp.*, vol. **29**, no. 1, pp. 406–420, Jul. (2019), doi: 10.1002/j.2334-5837.2019.00611.x.
12. C. G. Awuchi, "HACCP, quality, and food safety management in food and agricultural systems," *Cogent Food Agric.*, vol. **9**, no. 1, p. 2176280, Dec. (2023), doi: 10.1080/23311932.2023.2176280.
13. L. R. Luiz, J. B. Inocêncio, L. L. P. Espindola, L. G. D. Almeida, A. S. R. Júnior, and L. M. R. D. Santos, "Implementation of the Hazard Analysis and Critical Control Points (HACCP) system in the potatos chips industry with in batch process: Implantação do sistema de Análise de Perigos e Pontos Críticos de Controle (APPCC) na indústria de batatas chips com processo em batelada," *Concilium*, vol. **23**, no. 12, pp. 184–201, Jun. (2023), doi: 10.53660/CLM-1488-23H24.
14. J. Verma, M. Bimpizas-Pinis, and A. Ncube, "Integration of Methods for Sustainability Assessment of Potentially Circular Processes – An innovative Matrix Framework for

Businesses and Policymakers," *J. Clean. Prod.*, p. 144580, Jan. 2025, doi: 10.1016/j.jclepro.2024.144580.
15. P. Anand, S. D. Singh, P. N. Bhowmik, V. Boya, and S. Pandey, "Optimizing Agricultural Waste By-Products: A Machine Learning Approach for Sustainable Construction Practices," *Circ. Econ. Sustain.*, vol. **5**, no. 3, pp. 2407–2429, Jun. (2025), doi: 10.1007/s43615-024-00483-2.