Implementation of Cleaner Production Technology to Reduce Environmental Impact of Tofu Production

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Abstract: This study analyzes the implementation of clean production technology in small-to-medium-scale tofu industries, focusing on its economic, environmental, and social impacts. A case study was conducted at YS Tofu Semarang using qualitative methods, including in-depth interviews and field observations, to explore operational practices and identify challenges in adopting sustainable methods. The findings indicate that the potential use of bittern or *nigari*—a natural coagulant rich in magnesium and calcium—can offer multiple benefits, such as improving product quality, reducing environmental pollution and cost efficiency. In addition to producing tofu with a softer texture and enhancing its nutritional value, the integration of *nigari* may help mitigate odor issues commonly associated with liquid waste. Moreover, the study highlights opportunities for waste valorization, where tofu by-products are repurposed into organic fertilizer and livestock feed, thus supporting a circular economy. The novelty of this research lies in proposing the use of *nigari* as a cleaner production innovation in Indonesian tofu SMEs, which remains underexplored in existing literature, especially in the context of integrating environmental and economic co-benefits. To strengthen sustainability outcomes, the study recommends the gradual adoption of advanced waste management technologies and increased awareness among tofu producers. These strategies not only align with global sustainability goals but also enhance the competitive edge of traditional tofu industries.

Keywords: *Tofu, nigari, cleaner production, sustainability, cost efficiency*

CHROME JOURNAL Volume 1 Issue 2
Received 20 December, 2024
Accepted 28 December, 2024
Published 31 December, 2024
Online at https://journal.unika.ac.id
DOI: 10.24167/ chrome.v1i2.65454

1. Introduction

Tofu is a processed soybean food that came from China (Sunyoto et al., 2014). Over time, tofu has now become one of the most popular foods in Indonesia. Based on data from Statistical Centre Agency (Badan Pusat Statistik), tofu consumption in Semarang City reaches an average of 0.164 kg per capita per week, or around 8.5 kg per capita per year. This data reflects the popularity of tofu as a major food source due to its role as an important legumes-based protein alternative. Not only in Semarang, but also in many other parts of Indonesia, tofu is considered as a staple food that provides essential nutrients at an affordable price (Badan Pusat Statistik, 2024). One of the main reasons tofu is a favorite among the people is its relatively low price and its high protein content (Maukar et al., 2019) about 6% - 12% protein contained in tofu (Khofipah et al., 2023). In addition, tofu is also easily processed into a variety of delicious foods that suit local tastes. This makes tofu a practical and economical food solution.

However, despite the potential of tofu products as a nutritious food source, the production process often poses significant environmental challenges. Waste is the residue of the production process that is no longer used and needs to be managed properly so as not to cause pollution or degradation of the environment. (Rahayu et al., 2012) The waste generated is both liquid and solid. Solid waste in this production is generated from the remaining soybean cleaning, and tofu pulp. On the other hand, liquid waste from the process of cleaning soybeans, cleaning equipment, soaking, stacking, and when disposed of directly into the water will cause a foul smell and in a certain time can change color to black which will certainly pollute the environment, (Pagoray et al., 2021) (Haryanto et al., 2020). These wastes, if not treated wisely, will cause damage to the environment and disrupt other natural systems (Kurniawansyah et al., 2022b).

Research indicates that liquid waste from the tofu industry in Mojokerto contains extremely high pollution levels, with BOD reaching 2063 mg/L and COD 5135 mg/L, far exceeding environmental standards. Additionally, greenhouse gas emissions from tofu production amount to approximately 0.8–0.9 kg CO2-eq per kilogram of tofu produced (Derosya & Ihsan, 2025). Life Cycle Assessment (LCA) studies conducted in Semarang and Padang reveal significant environmental impact scores, with global warming potentials exceeding 4000 kg CO2-eq. Untreated liquid waste poses a serious threat to water quality and public health in surrounding communities. Therefore, the implementation of clean production technologies is urgently needed to reduce pollution and enhance the sustainability of the tofu industry.

One relevant approach to this challenge is to implement clean technology. Clean technology is defined as technology invented to promote sustainable development by reducing risks and streamlining production expenditures and processes, and is environmentally friendly (Siddhanti et al., 1996). In the context of tofu production, the application of cleaner production can be applied to minimize waste generation and prevent pollution in a production. (Bomantoro, 2016) "*How is the cleaner production implementation of YS tofu, Semarang*?" and this study is intended to (1) explain the process of tofu production; (2) identify the cleaner production practices conducted by YS Tofu Semarang; and (3) provide recommendation to improve tofu production.

2. Materials and Method

YS Tofu Factory was chosen as the research location after a search of SMEs in Semarang City from the Semarang City Small and Medium Industry Data Portal website. From the search, 3 SMI options were determined, namely the first is Banana Crisps SMI, the second is Lunpia SMI, and the last is YS Tofu SMI. Banana Crisps SMI has been contacted but is no longer producing and for the next we held discussions to determine between Lunpia SMI or YS Tofu SMI. IKM Tahu YS has been contacted and gave a good response to be able to conduct a mutually agreed meeting. The location of YS Tofu IKM is on Jl. Tandang Ijen Rt 1 / Rw 2, Jomblang Village, Candisari District. The data in this study were obtained with primary and secondary data. Primary data is data obtained directly from sources. Meanwhile, secondary data is data obtained from existing researchers (Ramdani & Farity, 2022). In addition, secondary data in this study were obtained from the Central Bureau of Statistics website. Primary data collection was conducted using qualitative methods, where researchers asked questions to industry players. Qualitative research is a type of research to obtain data from oral or observed words. In this case, the interview questions asked were in the form of a question guide with an open-ended nature.

When conducting interviews with related parties, it is important to plan what questions will be asked and what topics will be discussed. But before that, researchers and producers must have a definite meeting schedule. Then one week before conducting the interview, we organized the questions in the form of 5w+1h questions on the Google Docs application so that we could make edits at any time. After the list of questions was created, the researchers visited the industry and conducted the interviews. Primary data was obtained by interviewing for around 60-90 minutes and was conducted twice. Data during interviews with informants were collected in a summary of the results of interviews, observations, and documentation. with the interview was conducted at the industry on Friday, September 20, 2024, and on Wednesday, October 2, 2024. The first meeting was conducted with one of the employees in the industry (Mr. Suyanto) and discussed tofu production in general, and researchers analyzed the problems observed in the industry. In the second meeting, researchers dug deeper information related to problems in the industry with the industry owner (Mr. Hasan). The results of the interview were compiled as a written record used to identify cleaner production problems in the HS tofu factory.

During the interviews, the research team used mobile phones to take notes, record and take pictures during observations and interviews with relevant parties. After the conversation with the industry, the researchers observed the production area and took some pictures with the permission of the employees and/or the industry owner. On the same day, the research team began processing data from the information obtained from the informants. The results that were recorded and recorded were then dissected again and the informants' answers were put into the same google document as the questions that were previously assembled. After the data was put into one document, in the second week after the researchers began compiling in the journal.

3. Result and Discussion

During the initial meeting with one of the employees, it was gathered that the raw materials used in tofu production are soybeans, clean water, and vinegar. The equipment utilized includes a weighing scale, large containers (for cooking and coagulation), a boiler, a furnace, large buckets (to hold vinegar), a grinder, a tofu mold, a tool to extract vinegar while separating the solid tofu from the soaking water, knives, small tofu molds, buckets or barrels for distribution purposes, and plastic sheets as the base. The stages of tofu production are as follows:

> "*Soybeans are weighed using a weighing scale – Soybeans are washed with clean water and soaked for two hours – The soaked soybeans are ground into a slurry using a grinding machine – The soybean slurry is boiled in a container heated by furnace steam – The tofu pulp is filtered to separate it from the tofu liquid – The tofu pulp is mixed with vinegar in a separate container – The tofu pulp that has been mixed with vinegar is molded – The molded tofu is placed on a large flat rectangular container – The tofu is cut into square pieces of sizes commonly sold in the market.*"
>
> (Suyanto, interview on Friday, September 20, 2024)

In a day, this small-to-medium enterprise (SME) can produce up to 48 batches. Each production session requires 14 kg of soybeans, resulting in a daily soybean requirement of 672 kg and 16,000 liters of clean water. From this quantity, the SME can produce 96 buckets of tofu, each with a capacity of 8.4 kg. Each bucket contains 400–500 pieces of tofu, with the exact number varying based on the weight preference of the buyer. The SME offers tofu products weighing 3 ounces and 4 ounces. On average, the SME achieves a daily production weight of approximately 8.064 tons. To heat the boiler, the SME uses 1 ton of mixed soft and hardwood daily. Additionally, the production process requires 25 liters of vinegar for coagulation, which is stored in a single bucket and used as needed during the tofu coagulation process.

The second meeting was conducted with the SME owner, representing the second generation of the family business. The discussion focused on the SME's identity and historical journey. This industry was established in 1995, initially starting with home-based tempeh production. In the early 2000s, the first-generation owner received a heating furnace grant from a university. With the addition of this technology, the owner decided to expand the business line. Using the same base soybeans the owner ventured into tofu production, which was highly popular at the time. However, currently, only the owner’s tofu business and one other SME in a different village remain operational. Over its 29 years of operation, the SME has maintained its status as a small-to-medium enterprise, now capable of achieving a high daily production volume.

The preparation of scripts and a list of questions to be used during interviews with the industry stakeholders allowed us to gather responses from the local community and the IPAL (Wastewater Treatment Plant) management in the area. Based on the initial feedback provided by Mr. Edi, the presence of the industry has been generally well received by the community. This positive perception is largely due to the benefits it brings, particularly to creating job opportunities that enhance the welfare of the local population. However, alongside this positive reception, certain concerns have been raised by the residents. These concerns primarily revolve around the management of waste generated from the tofu production process, including liquid waste and ash waste. If not properly managed, these types of waste could have a direct negative impact on the environmental quality and the well-being of the communities surrounding the industrial area. Addressing these issues is crucial for ensuring the sustainability of industrial operations and fostering harmonious relationships with the local community.

The second response was provided by Mr. Hendra, who serves as the IPAL caretaker. He highlighted that this industry, along with small and medium enterprises (SMEs) in the Candisari area, has implemented relatively good waste management practices. However, there are still shortcomings that require attention, particularly concerning the lack of worker discipline. It was noted that non-liquid waste items often enter the drainage system, causing blockages in the wastewater flow. At certain times, this issue can lead to leaks that inconvenience nearby residents, especially those living along the wastewater drainage routes.

The subsequent discussion with the owner revolved around the challenges faced by the SME. Over the years, several issues have arisen: (1) Air Pollution, because the smoke from wood combustion used for cooking cannot be adequately controlled, leading to airborne residue that affects the surrounding environment. The ash from combustion also disperses, potentially impacting the belongings of nearby residents; (2) Tofu Waste management, because managing tofu pulp waste and rejected products remains a challenge. Rejected products are pieces that do not form perfect squares; (3) Wastewater Disposal, because the drainage system for wastewater management is often clogged, resulting in inefficient disposal of water used during the production process.

Other industries face similar challenges to the tofu factory we are studying, such as the tofu factory located in Trimurti Village, Srandakan District, Bantul Regency. Some industries in this area have adopted the concept of clean production, one example being the use of Wastewater Treatment Plants (WWTPs). However, they still encounter similar issues, such as discharge channels that frequently exceed capacity (overload), become clogged, and lead to leaks. Furthermore, there are still some industrial operators who openly dispose of liquid waste without undergoing any treatment, either through WWTPs or independent waste management systems. (Budiarti, 2016) .

The first issue has been addressed by modifying the shape of the smoke funnel, ensuring that flying ash no longer causes discomfort to nearby residents. The second issue can be resolved by collaborating with other parties to utilize the tofu pulp effectively, for instance, by supplying it to livestock farms. Additionally, rejected tofu products can be repurposed as raw materials for processed tofu-based products. A simpler solution would involve inviting external partners to manage the rejected tofu. The third issue, related to clogged wastewater drains, can be mitigated through improved regulation and discipline among SME employees, ensuring that all parties involved contribute to the common good. From the author's analysis, this tofu-producing SME has already implemented clean technology, as evidenced by the existence of a shared wastewater management channel. However, its functionality remains suboptimal due to inadequate control over the wastewater flow. Considering the cultural and technical work habits of the SME, the author recommends the use of coagulants that support cleaner production processes.

One key recommendation is to replace vinegar as the coagulant in tofu production with bittern or *nigari.* This substitution offers a step toward cleaner production practices. Bittern, also known as *nigari* or magnesium chloride ($MgCl_2$), is one of the most used coagulants in tofu manufacturing. Derived as a byproduct of seawater evaporation or sea salt production, this substance is favored in the tofu industry for its ability to coagulate soymilk proteins, resulting in a smooth and chewy tofu texture.

Nigari is sourced from salt production residues and contains over 80 essential minerals beneficial for human health, such as magnesium, potassium, calcium, boron, zinc, and selenium. These minerals play significant roles in various metabolic processes in the body. The composition of nigari makes it a healthier alternative compared to traditional coagulants like vinegar (Wahyudi et al., 2022). By adopting nigari as a coagulant, the SME can enhance its clean production initiatives. This substitution not only aligns with environmentally friendly practices but also contributes to producing tofu with improved texture and nutritional value, benefiting both the industry and consumers (Napid et al., 2022).

Nigari and vinegar are both effective coagulants in tofu production; however, nigari demonstrates superior performance overall. Vinegar at concentrations of 3–5% can accelerate protein coagulation within 0.78 minutes and yield up to 23.73% (Yépez et al., 2024) but requires a relatively high volume. In contrast, *nigari* (0.3–0.5%) produces firmer, more stable tofu with significantly lower dosage. Environmentally, vinegar generates wastewater with high organic loads BOD ranging from 3,667 to 4,933 mg/L and COD between 7,668 and 9,736 mg/L (Hartini et al., 2021,) posing pollution risks if untreated. Meanwhile, nigari produces magnesium hydroxide [$Mg(OH)_2$] sludge, which is more environmentally benign and easier to manage. Thus, *nigari* is more efficient, cost-effective, and environmentally sustainable for tofu production.

Nigari exhibits several effects when dissolved in water. One notable effect is the enrichment of the water's mineral content. Rich in magnesium and chloride, *nigari* enhances the nutritional value of water, especially when it is used in the production of food or beverages. Additionally, *nigari* influences the pH level of water. While the pH change is not significant, *nigari* can make the water slightly more acidic depending on the concentration used as reported by Utomo (2015).

In the context of food production, *nigari* helps retain moisture, particularly in tofu-making. This contributes to achieving the desired tofu texture, enhancing the quality of the final product (Siami, 2015). *Nigari* plays a crucial role in protein coagulation, especially during tofu production. As a coagulant, *nigari* facilitates the precipitation of proteins in soy milk, which is a fundamental step in tofu formation. This process ensures that the tofu achieves both optimal texture and stable consistency for further processing. The use of *nigari* as a coagulant in tofu production generates significantly less liquid waste compared to vinegar, with volumes of 25 ml versus 225 ml, respectively. The liquid waste from *nigari* exhibits a more neutral pH of 6.7 and is odorless, in contrast to the acidic waste from vinegar with a pH of 4.8. Furthermore, tofu produced using *nigari* contains a higher protein content of 18.3 grams and a lower fat content of 3.99 grams, whereas tofu made with vinegar contains 17.4 grams of protein and 10.9 grams of fat. Thus, *nigari* not only substantially reduces liquid waste but also enhances the quality of tofu (Wahyudi et al., 2022).

Moreover, *nigari* contains magnesium chloride, which has antimicrobial properties. These properties can extend the shelf life of food products by inhibiting the growth of bacteria and other microorganisms, thereby preserving the quality and safety of the produced food. *Nigari* also positively impacts the flavor profile of food. In tofu production, *nigari* imparts a distinctive umami flavor, improving the taste quality of the final product and making it more appealing to consumers.

Beyond the food industry, nigari has applications in agriculture. As a mineral fertilizer, it can improve soil quality and provide additional nutrients to plants (Imadani, 2017) When used in irrigation systems, *nigari* enriches soil nutrients, leading to better crop yields. This benefit is especially significant for regions with less fertile soils plants (Permatasari & Vienastra, 2022)

In addition to its agronomic advantages, *nigari* also plays an important role in human health. Magnesium, a key component of *nigari*, is an essential mineral required by the body to support muscle function, the nervous system, and bone health. Adding *nigari* to water can help meet daily magnesium needs and maintain electrolyte balance, which is vital for daily activities and long-term health (Imadani, 2017).

However, the large-scale use of nigari requires careful monitoring to prevent environmental impacts. Wastewater containing *nigari*, if discharged directly into aquatic systems, can increase salinity or mineral concentrations in the water. Such changes can affect aquatic ecosystems, including the flora and fauna within them. Elevated salinity levels may disrupt the balance of aquatic environments, potentially harming organisms sensitive to changes in water chemistry (Kurniawansyah et al., 2022a). Therefore, the use of nigari in production processes must be accompanied by effective waste management to mitigate environmental impacts.

In conclusion, *nigari* offers numerous benefits, ranging from nutritional enhancement, improved texture, and flavor in food production to agricultural applications and health advantages. However, its potential negative environmental impacts must be a primary consideration. A responsible approach to its use, including proper wastewater management, is crucial to ensuring that the benefits of *nigari* can be maximized without harming surrounding ecosystems.

The process of making tofu with *nigari* is fundamentally similar to conventional tofu production but uses a nigari solution as the coagulant to precipitate proteins in soy milk. Here is an example of *nigari* application with an experiment of 1kg of soybeans. begins with preparing the ingredients: 1 kg of soybeans, 7 liters of water for grinding and cooking, and 20 cc of *nigari* dissolved in 120 cc of water. This measurement is an example for producing 20–25 pieces of tofu, each weighing 3–4 ounces. Optionally, sugar can be added to the residual whey for enhanced flavor.

The initial step involves thoroughly washing the soybeans to remove impurities or residual husks. After cleaning, the soybeans are soaked in water for approximately four hours. This soaking process allows the soybeans to swell, making them easier to grind in the subsequent steps.

Once soaked, the softened soybeans are ground using a blender or grinding machine, combined with 7 liters of water to produce smooth soy milk. The soy milk is then filtered to separate the *okara* (soy pulp), leaving only pure soy milk. This filtering step ensures the soy milk is free from coarse particles, which might affect the tofu's final texture.The filtered soy milk is then heated to a boiling point. This step sterilizes the liquid, making it safe for consumption, and prepares the soy proteins for coagulation when the nigari solution is added.

Next, the nigari solution (20 cc of nigari dissolved in 120 cc of water) is slowly poured into the boiling soy milk while gently stirring. The careful mixing ensures even distribution of the nigari solution, optimizing the coagulation of soy proteins. Within moments, the proteins in the soy milk begin to curdle, forming tofu curds separate from the whey. This reaction, driven by the magnesium chloride in nigari, is the cornerstone of tofu production.

The tofu curds are then separated from the liquid whey using a skimmer or strainer. The curds are transferred into tofu molds, where the shaping process begins. The curds are pressed using a tofu press to form a firm, stable texture. This pressing step also removes excess liquid, resulting in a more compact tofu block. After pressing, the tofu is left in the mold to cool down to about 50°C. This cooling process is crucial to maintaining the tofu’s shape and texture when removed from the mold. Once cooled, the tofu is ready for consumption or storage. For storage, tofu is often submerged in clean water to retain its moisture and prevent the texture from hardening.

Tofu made with nigari offers several advantages, such as a softer texture and a distinctive umami flavor. Additionally, using nigari increases the mineral content, particularly magnesium, which provides health benefits. Nigari is recognized as a natural coagulant, making it a more environmentally friendly option than synthetic chemicals, suitable for both household and industrial-scale production.

Producing tofu with nigari offers significant advantages for business owners in terms of cost efficiency, improved product quality, and reduced environmental impact. A notable cost-saving benefit is the reduced water usage. Nigari-based tofu production requires only 7–10 liters of water per kilogram of soybeans, significantly less than conventional methods using vinegar. Lower water consumption not only cuts operational costs but also contributes to water conservation efforts.

This method also eliminates odorous solid and liquid waste, reducing waste management costs and mitigating the risk of environmental fines. Such savings are particularly beneficial for small-scale businesses aiming to lower operational expenses without compromising product quality.

In terms of quality, tofu made with nigari contains higher nutritional value, particularly magnesium and calcium, compared to conventionally produced tofu. These minerals appeal to health-conscious consumers, offering an added value that enhances market competitiveness. Furthermore, the tofu's texture is softer, and its flavor is superior to that of tofu made with other coagulants. This improved taste and texture can boost customer satisfaction, drive sales, and foster consumer loyalty. Consequently, using nigari opens opportunities to create premium products with a competitive edge in the market.

Nigari-based tofu production is also more environmentally friendly. Unlike traditional methods, it does not generate odorous waste that can pollute the surroundings. The residual liquid from production, known as "tofu water," contains minerals and maintains a neutral pH. This liquid can be repurposed as a nutritious beverage, creating opportunities for product diversification.

Additionally, the leftover soybean pulp (*okara*) can be utilized as animal feed or in other products, ensuring no waste is discarded unnecessarily. By repurposing byproducts, producers not only reduce environmental impacts but also create additional revenue streams.

Overall, producing tofu with nigari not only yields high-quality products but also adds value in terms of health and environmental sustainability. The simple yet effective process of using nigari as a coagulant creates tofu that is flavorful, nutritious, and eco-friendly. This method presents an excellent alternative for tofu producers seeking to improve product quality while supporting sustainable practices. Nigari-based tofu production aligns with modern consumer preferences for health and environmental consciousness, making it an advantageous choice for businesses.

From a sustainability perspective, the tofu production method using nigari offers added value by promoting the image of an environmentally conscious company. As consumers become increasingly aware of environmental issues, they tend to prefer products manufactured through eco-friendly practices. By incorporating nigari, producers can highlight sustainable production methods, broaden market reach, and attract environmentally conscious customer segments. Moreover, this method supports better resource management by utilizing all by-products generated during the production process.

Overall, producing tofu with nigari provides significant benefits in terms of cost efficiency, product quality, and environmental impact. By optimizing resource use, minimizing waste, and creating nutrient-rich products, producers can enhance their market competitiveness while contributing to environmental conservation. This combination of benefits positions nigari as a practical yet strategic choice for developing a sustainable tofu business (Dwijayani & Hadi, 2013)

Using nigari as a coagulant in tofu production provides significant competitive advantages in the marketplace, especially in meeting the demands of consumers increasingly focused on health and sustainability. Nigari, a natural, mineral-rich substance, imparts unique qualities to tofu products. In the health and organic product segment, this innovation distinguishes nigari-based tofu from conventional tofu made with vinegar or synthetic coagulants. This added value creates strong appeal among consumers seeking high-quality food alternatives with greater health benefits.

The magnesium and calcium content in nigari tofu not only enhances its nutritional value but also contributes to a superior taste and texture compared to similar products on the market. These qualities make nigari tofu an ideal candidate for premium product positioning, appealing to health-conscious individuals and niche markets such as vegetarians, vegans, and those following plant-based diets (Imaniyah, 2020)

The rising awareness of healthy eating habits and the environmental impact of food production processes presents significant opportunities for nigari tofu producers to expand their market share. Nigari tofu can be marketed as a premium, eco-friendly product, attracting sustainability-conscious consumer segments. By emphasizing these advantages, producers can strengthen their foothold in local markets while exploring opportunities in international markets increasingly receptive to healthy and sustainable products.

In many countries, the trend toward organic and natural foods continues to grow, creating stable demand for products like nigari tofu. This trend allows nigari tofu producers to address specific market needs with tailored marketing strategies. For example, educating consumers about the health benefits and environmental advantages of nigari tofu can enhance brand value and foster customer loyalty (Imadani, 2017)

Product packaging also plays a vital role in reflecting a commitment to health and sustainability. Utilizing recycled materials or including transparent information about the production process can further resonate with eco-conscious consumers. By aligning product messaging with global market trends, producers can effectively communicate the uniqueness and value of nigari tofu.

The competitive edge of nigari tofu lies not only in its product quality but also in how producers can leverage global market trends. Modern consumers are increasingly concerned with how products are made, including their impact on the environment and society. By adopting nigari in tofu production, producers can establish themselves as pioneers in creating healthy, environmentally friendly foods.

This commitment to sustainability not only enhances product appeal but also instills consumer trust in supporting the brand. Producers who champion these values are better positioned to capitalize on evolving consumer preferences, thereby increasing their brand's market relevance and longevity.

In conclusion, utilizing nigari as a coagulant in tofu production creates substantial opportunities for enhancing market competitiveness. This innovation allows producers to offer products with added value, aligning with modern consumer preferences for health and sustainability. Through targeted marketing strategies, nigari tofu can dominate the healthy and organic market segment, generate strong demand, and open pathways for international market expansion.

4. Conclusions

The tofu production process at YS Small and Medium Enterprises (SMEs) relies on key ingredients, including soybeans, clean water, and vinegar as a coagulant to coagulate soybean protein. However, this production process faces several significant environmental challenges, such as the generation of liquid and solid waste that remains inadequately managed, as well as air pollution caused by the combustion of wood as an energy source. These challenges present critical issues that need immediate attention to enhance the sustainability of the production process.

Although the use of nigari is recommended as an alternative coagulant in support of clean production principles, it is important to note that this study has not yet conducted direct testing on the application of nigari within the actual tofu production process at YS SME. Therefore, any conclusions regarding the effectiveness of nigari in reducing environmental impacts or improving tofu quality remain hypothetical and should be treated as a potential area for future research. This represents a limitation in the present study that warrants further empirical validation.

Currently, the application of clean production principles at YS Tofu SMEs is not yet fully integrated into their operational systems. This is evident from the unstructured waste management system and the challenges in managing the disposal of liquid waste, which has the potential to pollute the surrounding environment. To address these issues, the use of nigari as an alternative coagulant is recommended as an innovative step toward implementing clean production technology. Nigari not only serves as a substitute for vinegar as a coagulant but also offers additional benefits, such as reducing the odor associated with liquid waste typically generated during the production process. Moreover, nigari contributes to improving the quality of tofu by providing a softer texture and enriching its mineral content, including magnesium and calcium. By adopting nigari as part of the production process, YS Tofu SMEs are expected to achieve a more environmentally friendly, efficient, and sustainable production process without compromising the quality of the final product.

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