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From tradition to transformation: a scientific blueprint for safer tofu in Bandar Lampung

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ABSTRACT

Tofu is an affordable, ubiquitous protein source, but its production, especially in small and medium-sized enterprises (SMEs) using traditional methods, presents significant microbiological risks. To address these risks, we analyzed the production process of a local producer, "tahu Bandung SMS" in Bandar Lampung, using the Hazard Analysis and Critical Control Point (HACCP) system. Our investigation identified 23 biological, chemical, and physical hazards and established five critical control points (CCPs) at the filtering, coagulation, printing, and packaging stages. The primary outcome is a producer-specific HACCP plan detailing critical limits, monitoring protocols, and corrective actions. This study provides a practical framework for "tahu SMS" to improve food safety and offers a replicable model for integrating scientific safety principles into traditional tofu production.

Keywords: Critical Control Point (CCP); food safety; Hazard Analysisis Critical Control Point (HACCP); tofu production

INTRODUCTION

Tofu, a traditional food made from soybeans, is a significant source of protein for many people, particularly in Asia (Chen et al., 2023). Its popularity is growing globally as a vegan alternative (Sapieja, 2017). In Indonesia, tofu is an important part of the daily diet and a key product for many small and medium-sized enterprises (SMEs) (Triyanni et al., 2017). One such enterprise, "tahu Bandung SMS" in Bandar Lampung, is a local producer contributing to the region's food supply. However, the very nature of tofu, with its high moisture and protein content, makes it an ideal medium for microbial growth, posing potential food safety risks.

The tofu production process, from soaking soybeans to pressing the final product, presents multiple opportunities for contamination by spoilage and pathogenic microorganisms. Common microbial hazards include bacteria such as *Bacillus cereus*, which can form heat-resistant spores, and other cold-tolerant microorganisms that can thrive even under refrigeration (Matsui et al., 2022). These contaminants can lead to foodborne illnesses and economic losses due to spoilage. The wastewater from tofu production can also contain high levels of organic matter, which can negatively impact the environment if not treated properly (Taufikurahman et al., 2024).

To address these safety concerns, a systematic approach to food safety management is crucial. The Hazard Analysis and Critical Control Point (HACCP) system is an internationally recognized framework that focuses on preventing hazards rather than relying on final product testing (Fadilah et al, 2024). It involves identifying potential biological, chemical, and physical hazards at each stage of production and establishing controls to mitigate them (Rifqie et al., 2019). The implementation of HACCP, along with Good Manufacturing Practices (GMP), is essential for ensuring the quality and safety of food products (Triyanni et al., 2017).

This research will conduct a detailed microbiological analysis of the tofu production process at "tahu Bandung SMS" in Bandar Lampung. The study will identify the critical control points (CCPs) within their specific production line and develop a tailored HACCP plan. By doing so, this research aims to not only improve the safety and quality of the tofu produced by "tahu Bandung SMS" but also to provide a practical model for other tofu SMEs in Indonesia to enhance their food safety practices and ensure consumer health.

METHODOLOGY

1. **Research design**

   This study adopted a descriptive research design, focusing on the systematic analysis of HACCP principles within the tofu manufacturing process. The primary objective was to identify potential hazards, establish critical control points (CCPs), and propose effective control measures to ensure food safety and quality in tofu production (Lindawati et al., 2022).

2. **Study location and scope**

   The research was conducted at a tofu production facility, specifically a home industry setting, to observe real-world application and challenges in implementing food safety management systems. The scope of the study encompassed the entire tofu production chain, from raw material reception to the final packaging of the product (Lindawati et al., 2022)

3. **HACCP team formation**

   A multidisciplinary HACCP team was established, comprising individuals with expertise in various aspects of tofu production, food microbiology, food chemistry, engineering, and quality assurance. The team was responsible for conducting the hazard analysis, identifying CCPs, and developing the HACCP plan.

4. **Product description and flow diagram**

   The product under investigation was traditional tofu, a soft solid food product derived from glycine-type soybeans. A comprehensive flow diagram of the tofu production process was developed, detailing each step from raw material preparation (e.g., soybean soaking, grinding) through cooking, filtering, coagulation, pressing, cutting, and packaging. This diagram served as the foundation for identifying potential hazards at each stage (Lindawati et al., 2022).

5. **Hazard analysis**

   A thorough hazard analysis was performed for each step of the tofu production process to identify potential biological, chemical, and physical hazards. This involved biological hazard, chemical hazard and physical hazards. he risk associated with each identified hazard was evaluated based on its likelihood of occurrence and severity of potential harm. High-risk categories were particularly noted in processes such as cooking, filtering, clumping, and forming.

6. **Critical Control Point (CCP) determination**

   Critical Control Points (CCPs) were identified using a decision tree approach, in accordance with HACCP principles. Based on the hazard analysis, specific steps in the tofu production process were determined to be critical for controlling identified hazards.

7. **Establishment of critical limits**

   For each identified CCP, critical limits were established. These are maximum or minimum values to which a biological, chemical, or physical parameter must be controlled at a CCP to prevent, eliminate, or reduce to an acceptable level the occurrence of a food safety hazard.

8. **Corrective actions**

   Predetermined corrective actions were established for each CCP to be implemented when monitoring indicates a deviation from critical limits. These actions aimed to bring the process back into control and to address any affected product. Corrective actions might include adjusting process parameters, re-processing, or holding and evaluating affected products.

9. **Data collection and analysis**

   Data pertinent to the tofu production process and HACCP implementation were collected through direct observation, interviews with workers and management, and analysis of existing production records. The collected data, particularly regarding hazard analysis and CCPs, were analyzed descriptively, often using univariate analysis, to identify key areas for improvement and control. The assessment of non-conformities against established food safety requirements, such as those issued by BPOM (Badan Pengawas Obat dan Makanan - Indonesian Agency for Drug and Food Control), was also conducted.

RESULTS AND DISCUSSION

1. **Pre-requisites of the HACCP Systems**

   The effectiveness of a Hazard Analysis Critical Control Point (HACCP) system in tofu production relies heavily on the diligent implementation of prerequisite programs, namely Good Manufacturing Practices (GMP) and Sanitation Standard Operating Procedures (SSOP). These programs establish the foundational hygienic and operational conditions essential for safe food processing. An assessment of the Tahu Bandung SMS Industry, conducted according to Indonesian regulations (PERKA NOMOR HK.03.1.23.04.12.2206 TAHUN 2012), revealed an overall "very good" compliance rate for GMP at 87.14% and for SSOP at 79.25%.

This indicates a strong commitment to fundamental food safety principles, aiming to enhance consumer trust, improve industry image, and expand market access.

Despite the high overall compliance, detailed analysis of the GMP revealed several "major" deviations, posing significant risks to product safety. Key areas requiring immediate attention included structural integrity, where doors, windows, and ventilation openings in the production area lacked insect screens, creating potential entry points for pests and contaminants. Furthermore, hygiene facilities were found to be deficient, with handwashing stations missing soap and drying towels, and toilets lacking proper signage to remind employees about handwashing protocols. Employee hygiene also presented a significant "major" non-compliance, as workers frequently did not wear complete Personal Protective Equipment (PPE), such as aprons, head coverings, gloves, and masks, increasing the risk of cross-contamination from personnel to the product. These critical shortcomings necessitate urgent corrective actions to mitigate serious food safety hazards.

Similarly, the SSOP evaluation, while generally positive, highlighted crucial areas for improvement. A primary concern was the unverified quality of the well water used in production, as it had not undergone laboratory testing to confirm its compliance with clean water standards, posing a potential microbiological and chemical hazard. Additionally, despite efforts to separate food and non-food items and adhere to chemical usage guidelines, the use of open PE plastic packaging during the critical packaging stage created a vulnerability to external contamination. Furthermore, while pest control measures were in place, the continued presence of insects indicated an insufficient integrated pest management strategy.

In conclusion, while the Tahu Bandung SMS Industry demonstrates a commendable foundation in food safety through its high overall GMP and SSOP compliance, the identified "major" deviations within both prerequisite programs represent critical vulnerabilities. Addressing these specific issues—such as installing insect screens, ensuring full PPE compliance, verifying water quality through testing, and improving packaging integrity—is paramount. Rectifying these shortcomings will not only enhance product safety and quality but also strengthen the overall food safety management system, paving the way for the successful and effective implementation of HACCP principles.

2. Assemble HACCP Team

The HACCP Team should be established based on the organizational structure. This approach ensures the team's legal accountability. The HACCP team should comprise representatives from all departments within the company. The company owner should lead the HACCP Team due to their high authority in company control. The HACCP chairperson will instruct the secretary to monitor and implement HACCP in the production process.

The duties of each HACCP team member are divided based on their expertise:

Chairman:

- Manages and organizes task distribution within the HACCP team
- Ensures the education and training of team members' employees
- Is responsible for ensuring that the established food safety management system is implemented, maintained, and updated
- Socializes and ensures members increase awareness of the importance of meeting customer needs
- Compiles HACCP documents
- Approves food safety system documents and other supporting documents
- Manages the preparation of food safety system documentation.

Secretary:

- Maintains HACCP documents
- Records audit results and HACCP meetings
- Assists the chairman in compiling HACCP documents

Members:

- Coordinates and is responsible for the implementation of the food safety system in their respective departments
- Assists the chairman and secretary with administrative tasks, including typing and controlling documents
- Actively participates in implementing the HACCP system

3. Product description

Product descriptions for Tahu Bandung SMS Industry's tofu are defined according to Codex Alimentarius requirements. The Codex Alimentarius stipulates that each product description must include the product name, raw material origin, raw material reception method, food additives, the packaging material reception process, the final product, processing stages, packaging type, storage conditions, shelf life, label information, intended use, and target consumers. Table 1 provides a detailed analysis of these product descriptions for Tahu Bandung SMS Industry.

Table 1.
Product Description

Specification	Description
Product Name	Tahu Bandung SMS
Raw Material Origin	USA BOLA Soybeans: Supplied by a dedicated soybean vendor.
Raw Material Reception	Raw materials are delivered by car, quantities aligning with order specifications.
Food Additives	Acetic Acid (CH3COOH)
Packaging Material Reception	Packaging materials are delivered by car, quantities dependent on order volume.
Final Product	Tofu
Processing Stages	The processing sequence includes raw material weighing, washing, grinding, boiling, filtering, coagulation, molding, cutting, re-boiling of finished tofu, and packaging.
Packaging Type	Primary packaging consists of PE plastic bags (10 cm height, 8 cm diameter). Secondary packaging is an bucket.
Storage Conditions	Stored at room temperature.
Shelf Life	3 days at room temperature; 4-5 days under refrigerated conditions.
Label Information	Not provided (Indicated by "-")
Target Consumers	Suitable for consumption by all age groups.

4. Determination of tofu process flowchart

Figure 1 presents the operational process chart (OPC) for tofu production, derived from general observations. This flowchart aims to facilitate the identification of potential contamination sources and the development of effective control measures.

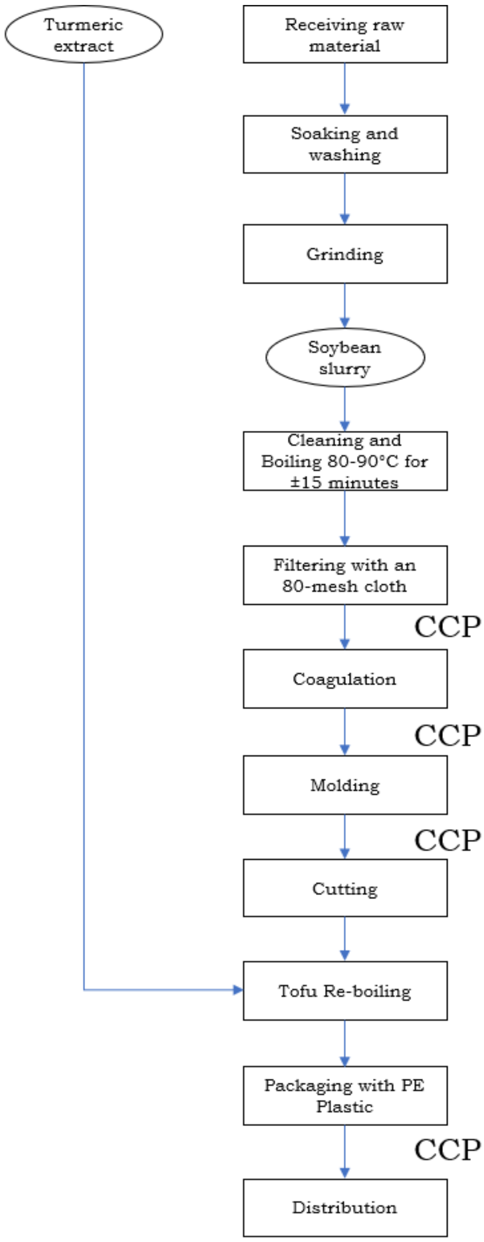

Figure 1. Determing the critical point (CCP) of the tofu

5. Hazard identification and analysis of materials and production process

Table 2 presents a comprehensive hazard identification for the tofu production process at Tahu Bandung SMS Industry, spanning from raw material reception to the distribution of the final product. This identification was conducted by observing each process stage for potential hazards impacting both product quality and consumer health. Generally, several studies on the physical, biological, and chemical quality of tofu production processes indicate potential contamination at every production stage (Jamiah et al., 2022). Based on these findings, Tahu Bandung SMS Industry must evaluate the identified hazards.

Table 2.
The summaries of potential hazard in processing of tofu

No.	Process/Stage	Hazard Category	Specific Hazard	Cause
1	Raw Material Reception	B	Mold, Pests, Sprouts	Storage area
		P	Gravel, Foreign objects	Storage area
		C	-	-
2	Raw Material Weighing	B	-	-
		P	Gravel, Foreign objects	Equipment used
		C	-	-
3	Soaking and Washing	B	*E. coli*, Coliform, *Salmonella*	Washing water
		P	Foreign objects	Environmental conditions
		C	-	-
4	Grinding	B	*Staphylococcus aureus*	Worker contamination
		P	Dirt, Foreign objects	Worker contamination, environmental conditions
		C	Metal	Equipment used
5	Boiling	B	*E. coli*, Coliform, *Salmonella*	Boiling water
		P	Foreign objects	Environmental conditions
		C	-	-
6	Filtering	B	*Staphylococcus aureus*	Worker contamination
		P	Foreign objects	Worker contamination, environmental conditions
		C	-	-
7	Coagulation	B	Mold	Equipment used
		P	-	-
		C	Acetic Acid (CH3COOH)	Usage exceeding 1:10 (v/v) ratio
8	Molding	B	*Staphylococcus aureus*	Worker contamination
		P	Standing water	Environmental conditions
		C	-	-
9	Cutting	B	*Staphylococcus aureus*, Mold	Worker contamination, environmental conditions
		P	Foreign objects	Environmental conditions
		C	-	-
10	Tofu Re-boiling	B	*E. coli*, Coliform, *Salmonella*	Re-boiling water
		P	Foreign objects	Environmental conditions

		C	-	-
11	Packaging	B	*E. coli*, Coliform, *Salmonella*	Soaking water (referencing prior step)
		P	Foreign object contamination	Equipment used, environmental conditions
		C	-	-

B is for Biology, P for physic, C for chemical

Several studies have identified and analyzed hazards throughout the tofu production process, from raw materials to the final product, covering biological, chemical, and physical contaminants. Raw materials like soybeans can be a source of various pathogens. *Bacillus cereus* spores, which are heat-resistant, can be present in soybean seeds and survive processing steps (Jin et al., 2025; Sapieja, 2017). Other bacteria identified in raw materials for plant-based products include *Escherichia coli* and *Salmonella* (from the *Enterobacteriaceae* family), *Listeria monocytogenes*, and *Staphylococcus aureus (Park et al., 2022; Sapieja, 2017)*. Soybeans are frequently infected by fungi such as *Aspergillus*, *Penicillium*, and *Fusarium*, which can produce mycotoxins like aflatoxins, deoxynivalenol (DON), zearalenone, and fumonisins (Jin et al., 2025; Sapieja, 2017). Aflatoxins can decrease when soybeans are heated, but many mycotoxins are heat-stable within typical food processing temperatures (80-121°C) (Sapieja, 2017).

Particles and heavy metals can be present in raw materials. Soybeans contain phytoestrogens, which have structural similarities to hormones and can bind to estrogen receptors (Jin et al., 2025). Persistent Organic Pollutants such as polychlorinated biphenyls (PCBs) and polychlorinated dibenzo-p-dioxins (PCDDs), can be found in plant-based raw materials, though less so in high-fat animal products (Jin et al., 2025). The tofu production process is susceptible to a range of hazards that can impact consumer safety, falling into biological, chemical, and physical categories. Biological contamination is a primary concern, with significant risks posed by pathogenic bacteria. For instance, strains of *Bacillus cereus*, which can produce harmful enterotoxins, have been identified in chilled tofu products (Park et al., 2022). Other bacteria like *Escherichia coli* can also be introduced, particularly if additional ingredients are used (Puspitawati et al., 2022). Furthermore, certain production methods, such as those for blue-mould and fermented "Mao-tofu," inherently involve microbial management, highlighting the risk of uncontrolled mold and bacterial growth, including organisms like *Lactobacillus* and *Trichosporon* (Li et al., 2025). Chemical hazards can be introduced through various means, including the improper use of additives and coagulantslike vinegar acid (CaSO4), contamination from raw materials with mycotoxins, or the formation of substances like histamine during fermentation (Lindawati et al., 2022). There is also a risk of contamination from cleaning agents and metal from processing equipment. Physical hazards, while less complex, are also present; these include foreign materials like dust and dirt, particularly during post-boiling cooling stages, and contaminants introduced by personnel, such as through smoking during production (Lindawati et al., 2022) To mitigate these diverse risks, key stages in the production process, including filtering, coagulation, molding, boiling, and packaging, have been identified as Critical Control Points (CCPs) where control measures are essential to ensure the safety of the final product(Lindawati et al., 2022; Triyanni et al., 2017).

6. Determination of critical control points (CCP) in the receiving materials

Critical Control Points (CCPs) are crucial steps implemented to prevent or eliminate hazards, ensuring a safe product (F. L. Bryan, *Analisis Bahaya dan Pengendalian Titik Kritis*. Departemen Kementerian Kesehatan R.). Determining CCPs for raw materials is particularly important, as raw material quality significantly influences the safety of the final product. The determination of CCP in the process of tofu industry is presented in Table 3.

Based on the established critical limits at Tahu Bandung SMS Industry, several production processes are identified as Critical Control Points (CCPs). Initially, the raw material reception process is *not* considered a CCP. This is because during the soaking process, unsorted materials such as twigs, gravel, soybean husks, and external contaminants can be eliminated through subsequent washing and boiling. Furthermore, the grinding process is also *not* a CCP, as raw materials can be cleaned prior to grinding. Similarly, boiling is *not* a CCP because the soybean slurry is heated using steam to 80-90°C, a process sufficient to eliminate microbes and other hazards in the raw material (Boleng, 2015).

Table 3.
Summary of CCP determination on raw material

No.	Process/Stage	Hazard Category	Specific Hazard	Q1	Q2	Q3	Q4	Is this a CCP?
1	Raw Material Reception	B	Mold, Pests, Sprouts	Y	N	Y	Y	NO
		P	Gravel, Foreign objects	Y	N	Y	Y	NO
2	Raw Material Weighing	P	Gravel, Foreign objects	Y	N	Y	Y	NO
3	Soaking and Washing	B	*E. coli*, Coliform, *Salmonella*	Y	N	Y	Y	NO
		P	Foreign objects	Y	N	Y	Y	NO
4	Grinding	B	*Staphylococcus aureus*	Y	N	Y	Y	NO
		P	Dirt, Foreign objects	Y	N	Y	Y	NO
		C	Metal	Y	N	Y	Y	NO
5	Boiling	B	*E. coli*, Coliform, *Salmonella*	Y	N	N	-	NO
		P	Foreign objects	Y	N	Y	Y	NO
6	Filtering	B	*Staphylococcus aureus*	Y	N	Y	Y	NO
		P	Foreign objects	Y	N	Y	N	YES
7	Coagulation	B	Mold	Y	N	Y	Y	NO
		C	Acetic Acid (CH_3COOH)	Y	N	Y	N	YES
8	Molding	B	*Staphylococcus aureus*	Y	N	Y	Y	NO
		P	Standing water	Y	N	Y	N	YES
9	Cutting	B	*Staphylococcus aureus*, Mold	Y	N	Y	Y	NO
		P	Environmental conditions	Y	N	N	-	NO
10	Tofu Re-boiling	B	*E. coli*, Coliform, *Salmonella*	Y	N	N	-	NO
		P	Environmental conditions	Y	N	N	-	NO
11	Packaging	B	*E. coli*, Coliform, *Salmonella*	Y	N	Y	N	YES
		P	Foreign object contamination	Y	N	Y	N	YES

B is for Biology, P for physic, C for chemical

However, the filtering process *is* identified as a CCP. This is due to observations of worker non-compliance, such as smoking in the production area. The potential for physical contamination from cigarette ash and foreign objects (e.g., dust from the production environment), coupled with a lack of preventive measures, makes filtering a CCP because of the significant physical hazards to the product. Following filtration, the soybean extract undergoes coagulation, which *is* designated as a CCP. At this stage, excessive use of acetic acid (CH3COOH) coagulant can pose health risks to consumers. Molding *is* also a CCP. During molding, physical hazards can arise from standing water in the production area, which may contaminate the tofu product.

Finally, the packaging process *is* the last identified CCP. After tofu is packaged in plastic containers, it is stored in buckets with water to prevent spoilage. Hazards at this stage include microbiological contamination by *E. coli* from the tofu soaking water and *Staphylococcus aureus* from worker sweat. Additionally, the absence of lids on the storage buckets allows for potential physical contamination by foreign objects and twigs from the surrounding environment.

7. **Verivication procedures of raw materials and production process**

Verification procedures are crucial for ensuring a HACCP plan's effectiveness. This involves applying various methods, including testing, analysis, and evaluation, to the monitoring systems (Stevenson, 1999). HACCP itself is a robust system designed to assess hazard levels, predict risks, and establish appropriate supervisory measures, focusing heavily on prevention and process control (Suklan, 1998). Its primary goal is to control potential hazards that could compromise food product safety. Implementing an HACCP plan requires compiling comprehensive information on CCP identification, monitoring procedures, corrective actions, and verification measures, all detailed in Table 4.

Research by Jamiah et al., (2022) on HACCP implementation in home-scale tofu production, titled "Identifikasi Potensi Bahaya Pangan Industri Tahu Skala Rumah Tangga dengan Pendekatan Konsep Hazard Analysis Critical Control Point (HACCP)," revealed persistent hazard sources throughout the production process. Consequently, producers must implement corrective actions to ensure their tofu products' quality and safety. That study pinpointed several Critical Control Points (CCPs) during soybean reception, boiling, soybean soaking, coagulation, packaging, and temporary storage. Variations in CCP identification among tofu producers stem from differences in their equipment, production capacity, and facility layout, which, in turn, lead to distinct hazard types.

Table 4.
Verification procedure on processing tofu

CCP Process	**Critical Limits**	**Monitoring Procedures**					**Corrective Actions**	**Verification**	**Documentation and Records**
		What	***How***	***Where***	***Who***	***When***			
Filtering process	No contamination of physical foreign matter in soybean milk.	Content of physical foreign matter found in soybean milk.	Observe physical foreign matter during filtration.	Filtration area.	Production Department Employee.	Every filtration process.	Filtering until no foreign matter.	Perform cleanliness check of filtration cloth every 2 weeks.	Record filtration cloth condition.
Coagulation process	Use of coagulant (vinegar) in the coagulation process as much as 1:10 (v/v).	Condition of coagulant (vinegar) usage as a coagulant.	Observe the condition of coagulant usage.	Coagulation process area.	Production Department Employee.	Every coagulatio n process.	Make SOP related to the use of acetic acid (CH_3COOH) coagulant so that the content is not limited.	Measurement of pH.	Checklist of coagulation process conditions.
Molding process	The molding area must have a minimum height of 1 meter.	Molding area has sufficient height.	Observe the height of the molding area.	Molding area.	QC Officer.	Every molding process.	Create a molding area with a height of 1 meter.	There is a molding area with a height of 1 meter.	Report on the height of each molding area.
Packaging process	Equipment used.	Use of equipmen t in the packaging	Observe every piece of equipment	Packaging area.	Production Department Employee.	Every packaging process.	Provide cover to the equipment used.	Check by QC officer on product packaging.	Checklist of every packaging process.

CCP Process	**Critical Limits**	**Monitoring Procedures**					**Corrective Actions**	**Verification**	**Documentation and Records**
		What	***How***	***Where***	***Who***	***When***			
		process.	used in the packaging process.						
Packaging process	Use of cooked water, such as boiled water, in the soaking process.	Use of cooked water in the soaking process.	Observe every type of water used for soaking.	Soaking area.	Production Department Employee.	Every soaking process.	Use cooked water.	Check by QC officer on product packaging.	Checklist of every soaking process.

CONCLUSION

This research has systematically dissected the tofu production process at "tahu Bandung SMS" in Bandar Lampung through the scientific lens of microbiology and food safety, culminating in a comprehensive Hazard Analysis and Critical Control Point (HACCP) plan. The investigation confirms the initial premise that tofu production, while a traditional craft, is fraught with microbiological risks that necessitate a modern, scientific approach to ensure consumer safety.

The study successfully identified 23 significant hazards, encompassing biological, chemical, and physical contaminants, which underscores the complexity of ensuring safety in tofu manufacturing. Through a rigorous application of the HACCP decision tree, five Critical Control Points (CCPs) were pinpointed in the production process: the filtering, coagulation, printing, and packaging stages. These CCPs represent the junctures where control is absolutely essential to prevent, eliminate, or reduce food safety hazards to an acceptable level. For instance, the coagulation step was identified as a chemical CCP due to the use of acetic acid, while the packaging stage presented both physical and biological CCPs from potential environmental contaminants and microbial growth in the soaking wate.

Ultimately, this study demonstrates that the application of HACCP principles offers a proactive and scientific solution to the inherent microbiological challenges of tofu production. By moving from a reactive to a preventive food safety paradigm, "Tahu Bandung SMS" can not only mitigate the risks of foodborne illness and spoilage but also enhance its brand reputation and consumer trust. The findings and recommendations presented in this paper serve as a valuable model for other small and medium-sized tofu producers in Bandar Lampung and beyond, illustrating a clear path toward modernizing traditional food production to meet contemporary standards of safety and quality. Future research should focus on the long-term evaluation of the implemented HACCP plan to measure its effectiveness in reducing microbial loads and to continuously refine food safety practices within the industry.

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