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Design of Fermentation Machine With Work System Evaluation Using Fishbone Diagram Method in Surabaya MSMES

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***Abstract*—Tempeh fermentation process in Micro, Small, and Medium Enterprises (MSMEs) in Surabaya is generally still carried out conventionally, without the support of tools that can control the temperature and fermentation environment stably. Process inefficiencies and product quality irregularities are the main problems that business actors often face. This research aims to design a tempeh fermentation machine based on working system evaluation using the Fishbone Diagram method as an effort to develop appropriate technology. The research method used was descriptive-qualitative with an engineering approach, which included observation, interviews, and field studies of three tempeh MSMEs in Surabaya. The results of the Fishbone Diagram analysis show that the main factors causing inefficiency include irregular work methods, lack of technical knowledge, lack of fermentation equipment, and unsupportive working environmental conditions. Based on the results of this evaluation, an MSME-scale fermentation machine was designed with automatic temperature control, a capacity of 10–15 kg per batch, and an ergonomic design. Trials show that the machine is able to maintain a stable fermentation temperature, produce tempe products with more consistent quality, and reduce the physical workload of business actors. This research shows that the work systems approach in technology design is able to produce solutions that are contextual, functional, and adaptive to the needs of MSMEs. These findings contribute to the development of science and technology in the fields of food technology, work ergonomics, and production equipment innovation based on local needs.**

***Keywords*: tempeh fermentation, MSME, fermentation machine, fishbone diagram**

I. INTRODUCTION

Micro, small, and medium enterprises (MSMEs) play a crucial role in supporting the national economy.[1], particularly in the food sector [2]. According to data from the Ministry of Cooperatives and SMEs in 2023, MSMEs contributed more than 60% to Indonesia's Gross Domestic Product (GDP) [3]. In addition to making a significant contribution to GDP, MSMEs also play a key role in creating jobs in the agriculture, fisheries, and food sectors. [4][5]. Tempeh is a traditional food product with high nutritional value and widespread consumption in Indonesia. Tempeh production, which relies on soybean fermentation using Rhizopus sp., is generally still carried out manually and conventionally, especially among MSMEs[6]. Unstandardized fermentation processes can potentially produce products that vary in quality, texture, and flavor. Furthermore, dependence on environmental conditions such as temperature and humidity without proper control can lead to fermentation failure, resulting in wasted raw materials and time. As part of Indonesia's culinary heritage, tempeh not only has economic value for home producers and small industries but also plays a crucial role in national food security.[7]

The Surabaya Tempe MSME Village, located on Jl. Tenggilis Kauman, Gg. Buntu 27 No. 10, Surabaya, faces challenges in its quest to survive in the Indonesian economy. The fermentation process in this MSME community still relies on wooden storage, resulting in suboptimal tempeh production during the rainy season or extreme temperatures. Furthermore, rising prices for soybeans and yeast have also led to a 40% decline in production and turnover by 2024.

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Figure 1. Storage of Fermented Tempeh at the Surabaya Tempeh MSME

In general, the tempeh-making process involves several stages: washing and cleaning, boiling, soaking, peeling, draining, cooling and drying, yeast application, packaging, and finally, incubation or fermentation.[8]. One key factor influencing the fermentation process is temperature. The optimal temperature for tempeh fermentation ranges from 30-35°C, with a humidity level of around 60%-80%. Unstable weather conditions can prevent the growth of Rhizopus oligosporus mold and can even lead to its death. [9].

For tempeh producers, temperature control is crucial because, historically, soybean fermentation into tempeh has often failed, which can reduce tempeh production due to unfavorable weather and temperatures. A device with a temperature setpoint of 33°C, 35°C, or 37°C is needed to regulate the temperature during the tempeh fermentation process in an effort to maintain temperature stability.[10]. Running a business is not an easy task; it is full of risks, both in terms of capital losses and damage to the products produced. [11]. The process of making tempeh, which is sourced from soybeans, requires precision and cleanliness to ensure good results and is suitable for consumption. The most important stage in the tempeh-making process that can determine the quality of the tempeh is during the fermentation and inoculation process. [12].

Despite the development of various technological innovations, the adoption of technology by MSMEs in the tempeh sector—particularly in the Surabaya area—remains very limited. Most business operators still rely on experience and traditional practices passed down through generations for the fermentation process, without the aid of specialized equipment or monitoring systems. This situation is exacerbated by a lack of awareness regarding the importance of evaluating work systems, leading to operational inefficiencies, human error, and unbalanced workloads.[13] To date, few studies have integrated a work-system approach—such as analyzing the root causes of process issues using the Fishbone Diagram method—with the design of fermentation equipment tailored to the specific operational characteristics of these MSMEs.

The Fishbone Diagram, or Cause and Effect Diagram, is a widely used quality analysis tool to systematically identify the causal factors of a problem. [14]. In the context of tempeh production, this method can be used to evaluate various sources of irregularity in the fermentation process, including human factors, methods, machines, the environment, and materials. With systematic mapping, fermentation machine design can be more precisely directed to address actual problems in the field.

The research gap (delta) arises from the lack of a holistic and contextual approach, namely, the design of appropriate technology accompanied by a comprehensive evaluation of the work systems of MSMEs [15]. Most previous research has focused solely on the technical aspects of the machine without considering the work patterns, workloads, or habits of the business owners as the primary users. Therefore, there is an urgent need to develop a tempeh fermentation machine that is not only technically efficient but also compatible with the needs, limitations, and work systems of tempeh MSMEs in Surabaya.[16].

Based on this background, the research questions are as follows: What are the main causes of inefficiency in the tempeh fermentation process in MSMEs in Surabaya? How can a tempeh fermentation machine be designed to address these issues based on a Fishbone Diagram analysis? And to what extent can the proposed tempeh fermentation machine design improve efficiency and consistent product quality in tempeh MSMEs?

The objectives of this research are to identify and analyze the root causes of problems in the tempeh fermentation process using the Fishbone Diagram method in tempeh MSMEs in Surabaya. To design an appropriate tempeh fermentation machine based on the results of the MSME work system analysis. To evaluate the effectiveness of the machine design in consistently improving process efficiency and tempeh quality.

With this approach, this research is expected to make a significant contribution to the development of appropriate technology based on the real needs of MSMEs and to enrich the

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scientific knowledge in the fields of industrial ergonomics and work systems engineering in the traditional food sector.

II. RESEARCH METHODS

This research uses a descriptive-qualitative approach with an engineering approach to designing appropriate technology products. In general, this research method combines two main approaches: first, a work system analysis based on problem identification using the Fishbone Diagram (Cause and Effect Diagram) method; second, the design of a tempeh fermentation machine based on the needs and field context obtained from the analysis results.

The descriptive approach is used to describe the actual conditions of the tempeh fermentation process in MSMEs, specifically regarding factors that cause inefficiency or inconsistent quality. [17]. Meanwhile, the engineering approach is applied in the development and design of the fermentation tool based on the results of the work system evaluation. This research is applicable because it produces a concrete product in the form of a fermentation machine and simultaneously provides solutions to real-life problems faced by tempeh MSMEs in Surabaya.

This research was conducted on several tempeh MSMEs operating in the Surabaya area, particularly in areas with a high concentration of home-based tempeh producers, such as Rungkut District and Tenggilis Mejoyo. The location selection was carried out purposively based on the following criteria: MSMEs actively and consistently produce tempeh at least 3 times a week, the fermentation process is carried out conventionally without the aid of modern tools, and MSMEs are willing to be research partners and are open to observation and interviews.

The research subjects consisted of MSMEs (owners and workers) directly involved in the tempeh production process, technical experts (technicians/engineers) to validate the machine design, and ergonomic consultants/work systems experts (if necessary) to verify the results of the fishbone analysis. Three MSMEs participated in this study, each with 2–3 key respondents (owners/workers), resulting in a total of approximately 9–10 informants.

To obtain comprehensive data, this study used the following data collection techniques:

a. Field Observation

Observations were conducted directly of the tempeh production process at each MSME. The main focus of the observations included: soybean preparation (soaking, boiling, peeling), yeast inoculation, fermentation (placement, time, temperature, environment), work system observations, task division, and production workflow. Data collected consisted of field notes, photo/video documentation, and work process observation sheets.

b. In-Depth Interviews

Semi-structured interviews were conducted with business actors to explore their perceptions, experiences, and challenges encountered during the fermentation process. Questions focused on experiences with fermentation failures, product quality variations, technical and non-technical issues in the work process, expectations regarding fermentation aids/machines, and work environment conditions and ergonomics.

c. Documentation Study

Secondary data was collected in the form of literature, scientific articles, and journals related to tempeh fermentation equipment design, work ergonomics, and the application of Fishbone Diagrams in work system evaluation. Production documents, schedules, and work records, if available, from MSMEs were also analyzed.

d. Literature Review and Comparative Study

References from national and international journals were used as comparisons in analyzing research results and assessing gaps between actual practice and scientific theory. This study also provided the basis for the principles of fermentation machine design and design validation.

The instruments used in this study included work process observation sheets, semi-structured interview guidelines, a Fishbone Diagram format to organize root causes, fermentation machine design sketches (paper design and CAD), an evaluation form and initial machine design trial, a tool functionality validation checklist, and instruments developed independently and tested for feasibility through initial trials before widespread use.

The research procedure consisted of six main stages, as follows:

a. Stage I: Preliminary Study

This stage included a literature search on the tempeh fermentation process and production aids, a site visit to MSMEs to identify partners willing to participate in the research, and initial identification of problems and field needs through

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exploratory interviews.

b. Stage II: Work System Observation and Interviews

Stage II began with direct observation of production activities. Data was then recorded via video, observation notes, and documentation of the physical conditions of the workplace. In-depth interviews were conducted to strengthen the observations and gather subjective information.

c. Stage III: Problem Evaluation Using a Fishbone Diagram

The data obtained was analyzed using a Fishbone Diagram to identify the root causes of inefficient work processes or inconsistent fermentation results. Factors analyzed included:

- Man: skills, work habits, workload.
- Machines: lack of tools, damage, and incompatibility.
- Materials: quality of raw materials, availability of yeast starter.
- Methods: unwritten SOPs, variations in fermentation techniques.
- Environment: room temperature, cleanliness, ventilation.

Based on the results of the root cause analysis using the Fishbone Diagram method, the dominant factors that will be the focus of the solution design will be determined.

d. Stage IV: Fermentation Machine Design

Based on the main findings, a tempeh fermentation machine was designed, taking into account the principles of energy efficiency (electricity savings, insulation system), automatic temperature control (using sensors and temperature controls), capacity appropriate for the MSME scale, ease of operation and maintenance by non-technicians, and design ergonomics (equipment height, working position, workload). The initial design was created in the form of hand sketches and a CAD (Computer Aided Design) model. Technical specifications were outlined, including materials, dimensions, control systems, and operating mechanisms.

e. Stage V: Manufacturing and Initial Trial

The machine was assembled on a prototype scale using locally available materials in Surabaya. After manufacturing and assembly were completed, an initial trial (alpha test) was conducted under controlled conditions, with parameters including fermentation temperature stability, fermentation duration, yield, and operator comfort.

f. Stage VI: Evaluation and Revision

Following the initial trial, an evaluation was conducted based on the technical performance of the machine, user satisfaction among tempeh MSMEs, and work efficiency and time values. If necessary, design improvements were made before larger-scale production of the machine.

III. RESULTS AND DISCUSSION

Based on observations and in-depth interviews with three tempeh MSMEs in Surabaya, it emerged that the fermentation process is still carried out conventionally, without the aid of temperature or humidity control devices. The fermentation process typically lasts between 24 and 48 hours, depending on weather conditions, room temperature, and the subjective experience of the entrepreneur. Some MSMEs even rely on instinct and habit (tacit knowledge) to determine the fermentation endpoint.

Production activities are carried out in closed spaces without ventilation and a proper temperature control system. The raw materials used vary depending on market prices, and tempeh starter is often inconsistently available. The MSMEs studied also lack written standard operating procedures (SOPs), resulting in inconsistent tempeh production from day to day.

In general, the main obstacles identified include dependence on environmental temperature, the lack of fermentation equipment or incubators, a lack of technical understanding of the fermentation process, substandard or worn-out work equipment, and unstable tempeh quality (odor, texture, and taste).

3.1 Fishbone Diagram Analysis

Through the Fishbone Diagram approach, five main groups of causes of inefficiency in the tempeh fermentation process were identified. The results of the fishbone diagram analysis conducted on the working system of the Surabaya Tempeh MSME are as follows.

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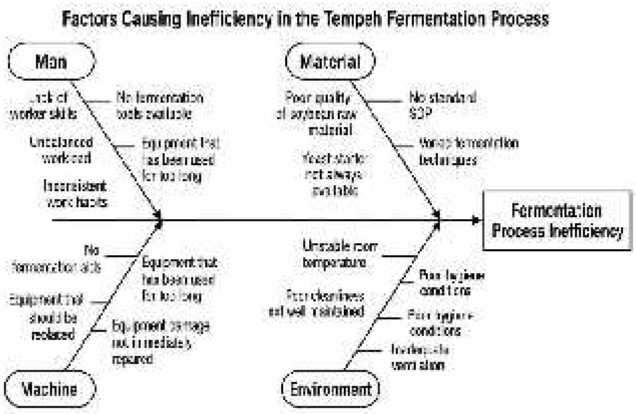

Figure 2. Fishbone Diagram Analysis

a. Human Factors

• Lack of worker expertise: Workers generally lack a food education background or specialized training related to fermentation. Knowledge is passed down through generations.

• Unbalanced workload: One person can handle multiple tasks, from soaking and peeling to inoculation to packaging.

• Inconsistent work habits: Each worker has a different approach and habits, resulting in variations in the final product.

b. Machine Factors

• Lack of fermentation aids: All fermentation processes rely solely on plastic containers and a natural environment without temperature control.

• Aging equipment: Many tools, such as fermentation vessels, scales, and sieves, are worn out or inaccurate.

• Damage is not promptly repaired: MSMEs tend to delay repairs due to limited funds and technical knowledge.

c. Material Factors

• Fluctuating quality of soybean raw materials: Local and imported soybeans are used interchangeably depending on market prices. Quality is not always stable.

• Yeast starter is not always available: Yeast is sometimes out of stock and substituted with other, less optimal sources.

d. Method Factors

• No standard SOP: All work steps are carried out based on experience, without written documentation or guidance.

• Fermentation techniques vary: There are differences in inoculation times, yeast quantities, and packaging techniques among workers.

e. Environmental Factors

• Unstable room temperature: There is no temperature control in the fermentation room. During the rainy season, the fermentation process often fails.

• Poor ventilation and poor hygiene: Closed rooms with poor air circulation and limited sanitation create the potential for contamination.

From this analysis, it was found that the lack of fermentation aids and the lack of temperature control were the dominant root causes, significantly impacting production quality and efficiency. This became the primary consideration in designing the fermentation machine to be developed.

3.2 Fermentation Machine Design

Based on the results of the work system evaluation and the identified problems, a tempeh fermentation machine was designed that meets the criteria of having automatic temperature control (using a temperature sensor and PTC heater/heating element), a small to medium capacity (10–15 kg per batch), thermal insulation for energy efficiency, an ergonomic design for ease of operation, and easy-to-clean food-grade stainless steel.

The first stage in the tempeh fermentation cabinet manufacturing process is product design. The design is carried out in two forms: 2D and 3D. The 2D design includes top, front, rear, and sectional views, while the 3D design is used to visualize the final appearance of the cabinet.

This design takes into account the fermentation space requirements, electronic component layout, ventilation, and user ergonomics. The placement of temperature and humidity sensors, fans, lights, and humidifiers is also planned from the outset to simplify installation and optimize the temperature inside the cabinet.

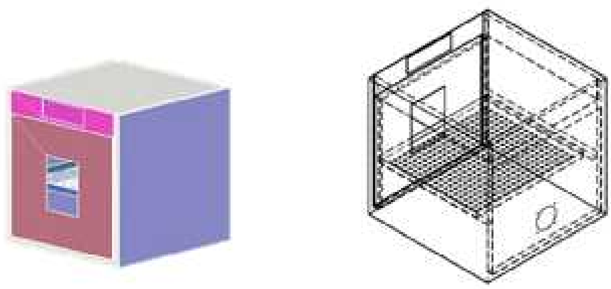

Figure 3. 3D Design of Fermentation Machine

Once the design is complete, the next step is to create the main cabinet frame. The main material used is a 1 mm-thick 304 stainless steel plate. This material was chosen for its rust resistance,

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malleability, and food-grade safety. The frame formation process involves the following steps:

- Cut the plate to the specified dimensions.
- Bend the plate on the right, left, and top sides to form the frame.
- Welding is performed at the joints between the front, back, bottom, and bent sides.
- After the assembly process is complete, smooth the joints and sharp surfaces using a grinder or sandpaper to avoid potential injuries and enhance the product's appearance.

At the rear of the cabinet, a special ventilation hole is made for the fan, measuring 8 cm x 8 cm, corresponding to the dimensions of the 220V AC fan to be installed. The purpose of installing this fan is to help regulate air circulation when the humidity inside the cabinet is too high and to maintain even temperature distribution. The holes were drilled using a power drill or metal cutting tool, using precision techniques to ensure smooth fan installation.

The cabinet door was constructed separately from the main body, measuring 55 cm x 50 cm. This door features a 14 cm x 19 cm square hole in the center, which will be fitted with 2 mm clear acrylic. This acrylic window allows users to view the fermentation process inside the cabinet without having to open the door, ensuring stable temperature and humidity.

The fermentation pan, measuring 41 cm x 45 cm, is equipped with 324 ventilation holes, each 1 cm in diameter. These holes maintain air circulation around the fermented soybeans, allowing the Rhizopus oligosporus fungus to grow evenly. The pan is also designed for easy removal and cleaning after the fermentation process is complete.

This step is part of the Functional Product Component (FPC) manufacturing process, which involves installing the electrical system and automatically controlling temperature and humidity. The equipment used includes:

- STC-3028 microcontroller: the primary device for measuring temperature and humidity.
- Temperature and humidity sensors: detect real-time conditions in the fermentation chamber.
- 3-watt heating lamp: serves as the primary heat source.
- 220V AC fan: activates when the temperature or humidity exceeds the set point.
- Ultrasonic humidifier module: generates water vapor to increase humidity if the relative humidity (RH) drops.

This system is designed to operate automatically based on the set point temperature of 33–35°C and humidity of 65–75%, according to the needs of tempeh fermentation. All cables are neatly arranged and insulated to prevent short circuits and ensure safety.

The final stage in manufacturing is product finishing, which includes the following activities:

- Cleaning all cabinet parts of welding residue, dust, and scratches.
- Rechecking the electrical system, such as testing sensors, activating fans, lights, and humidifiers.
- Simulating a fermentation trial to ensure stable temperature and humidity levels can be maintained for 24–48 hours.
- Evaluating the function of acrylic windows, doors, and locks to ensure there are no gaps for outside air to enter.

Figure 4. Results of the Tempe Fermentation Machine Design

Once this process is complete, the tempeh fermentation cabinet is declared ready to be used for tempeh production under controlled environmental conditions.

3.3 Fermentation Machine Performance Testing

Before the implementation of fermentation machines, MSMEs carried out the fermentation process using conventional methods that relied on ambient temperature for incubation. Consequently, the process was highly susceptible to weather fluctuations, often resulting in inconsistent tempeh quality. Following the design and assembly of the fermentation machine, preliminary trials were conducted to evaluate its ability to maintain temperature stability and

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improve fermentation success rates.

Testing was conducted by comparing the fermentation process using the conventional method and a fermentation machine, using the same batch size. The parameters observed included temperature stability, fermentation duration, product quality, and the fermentation success rate.

Table 1. Comparison of Test Results

No	Parameter	Conventional Method	Fermentation Machine	Improvement
1	Number of test batches	10 batch	10 batch	-
2	Batch successful	7 batch	9 batch	+2 batch
3	Success rate	70%	90%	20%
4	Fermentation temperature	28–38°C	33–35°C	More stable
5	Fermentation duration	24–48 hours	30–32 hours	More consistent
6	Tempeh texture	Partially sparse	Dense and uniform	Increase
7	Mycelium color	Uneven	Evenly white	Increase
8	Smell	Some batches smell sour.	The distinctive aroma of tempeh	Increase

Based on test results, the use of a fermentation machine increased the fermentation success rate from 70% to 90%. This improvement demonstrates that the machine's automatic temperature control system creates more stable fermentation conditions compared to conventional methods. With conventional methods, the fermentation chamber temperature is heavily influenced by environmental conditions, leading to frequent temperature fluctuations that hinder the optimal growth of the Rhizopus oligosporus mold.

In addition to improving fermentation success, the use of the machine results in more uniform tempeh quality. During testing, the fermentation chamber temperature was maintained within the 33–35°C range—the optimum temperature for mold growth. These conditions produced a denser tempeh texture, even mycelium coloration, and a more consistent aroma compared to conventional fermentation.

Thus, the designed fermentation machine is not only capable of increasing fermentation success by 20 percentage points but also ensures production process stability, potentially boosting productivity and reducing the risk of fermentation failure for MSMEs.

3.4 Performance Testing of the Fermentation Machine

Table 2. Temperature Stability

Time	Conventional	Machine
0 hours	31°C	33°C
6 hours	28°C	33°C
12 hours	35°C	34°C
18 hours	38°C	35°C
24 hours	30°C	34°C

To evaluate the performance of the designed fermentation machine, tests were conducted on several performance parameters, including fermentation temperature stability, fermentation duration, the fermentation success rate, and the time required for the operator to monitor the process. The test results demonstrated that the fermentation machine maintained the temperature within the 33–35°C range, whereas the conventional fermentation process exhibited temperature fluctuations between 28–38°C in response to changing environmental conditions. The average temperature deviation decreased from ±4.8°C with the conventional method to ±0.7°C when using the fermentation machine. This reduction in deviation indicates that the automatic temperature control system creates more stable fermentation conditions. In addition to temperature stability, the use of the fermentation machine increased the fermentation success rate from 70% to 90%.

Out of ten test batches, nine successfully produced tempeh meeting the required quality criteria, whereas the conventional method yielded only seven successful batches. These results indicate a 20-percentage-point increase in fermentation success. From an operational standpoint, the use of the fermentation machine reduced the time required for operator monitoring from approximately 90 minutes to 30 minutes per day, as temperature regulation is automated. Consequently, operators do not need to perform continuous checks throughout the fermentation process. Overall, the test results demonstrate that the developed fermentation machine outperforms the conventional method in terms of temperature

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stability, process efficiency, and product quality consistency.

3.5 Ergonomic Evaluation Using the REBA Method

To determine the impact of using the fermentation machine on the operator's working posture, an ergonomic evaluation was conducted using the Rapid Entire Body Assessment (REBA) method. The assessment focused on the operator's primary activities—loading soybeans into the fermentation chamber, retrieving fermentation trays, and monitoring the fermentation process—both before and after the machine's implementation. REBA evaluations were based on observations of the operator's body posture, specifically the positioning of the neck, back, legs, upper arms, forearms, and wrists, in accordance with the procedures established by Hignett and McAtamney (2000).

The assessment results indicate that the use of the fermentation machine improves the operator's working posture. Before using the machine, operators tended to work in a stooped position because the tempeh storage process involved wooden racks located close to the floor. After adopting the fermentation machine, the working posture became more upright; the machine's height was adjusted to the operator's elbow level, allowing for more comfortable loading and unloading of the fermentation trays.

Table 3. Ergonomics Assessment Results Using the REBA Method

Activity	Before the Engine	After the Engine	Decline
Adding the soybeans	9	4	-5
Retrieve the fermentation tray.	8	3	-5
Fermentation monitoring	6	2	-4
Average REBA Score	7,67	3	-4,67

Table 4. Risk Categories

REBA Score	Risk Level	Action
1	Very Low	No action required
2–3	Low	Needs monitoring
4–7	Moderate	Needs improvement
8–10	High	Needs immediate action
≥11	Very High	Needs immediate improvement

Based on the measurement results, the average REBA score decreased from 7.67 to 3.00. Before using the fermentation machine, the operator's working posture fell into the moderate-to-high risk category, necessitating corrective action. Following the machine's implementation, the REBA score dropped to the low-risk category, indicating that the machine's design successfully improved the operator's working posture.

The reduction in the REBA score is attributed to a change in the operator's working posture; previously, the operator had to bend over to arrange or retrieve *tempeh* from conventional fermentation racks. The designed fermentation machine features a working height of approximately 85–90 cm, allowing tasks to be performed in a more natural standing position. Furthermore, the use of a front door and a sliding rack system reduces the frequency of bending and excessive reaching. Consequently, utilizing the fermentation machine not only enhances the stability of the fermentation process but also improves the operator's ergonomic working conditions and potentially lowers the risk of musculoskeletal disorders.

IV. CONCLUSION

This study aims to design a tempeh fermentation machine that suits the needs of tempeh MSMEs in Surabaya with a work system evaluation-based approach using the Fishbone Diagram method. Based on the results of observations, interviews, and field analysis of the conventional tempeh production process. The inefficiency of the tempeh fermentation process in MSMEs is caused by various factors, namely: low worker skills and consistency (human factors), the absence of tools and poor equipment conditions (machine factors), fluctuations in the quality of raw materials (material factors), the absence of SOPs and varying production techniques (method factors), and an unconducive work environment such as unstable temperatures and poor sanitation (environmental factors). The Fishbone Diagram has proven effective as a tool to identify the main root causes of inefficiencies in the work process, thus providing a clear direction in designing appropriate solutions based on field needs. The developed tempeh fermentation machine design has the following specifications: automatic temperature control, small-medium capacity, thermal insulation, ergonomic design, and food-

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safe materials. This machine is designed to be easy to operate by MSMEs without requiring high technical skills. Initial trials have shown that the fermentation machine has succeeded in increasing efficiency and product quality. Temperature can be controlled stably, the fermentation process is more consistent, and the resulting tempeh is more uniform in texture, aroma, and appearance. Furthermore, the fermentation success rate increases from an average of 70% to over 90%. In terms of ergonomics and work systems, this machine reduces physical workload, simplifies fermentation monitoring, and increases workplace comfort, thus supporting the productivity and well-being of MSMEs

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