



Design and Performance Evaluation of a Semi-Automatic Milk Pie Dough Forming Machine for Small-Scale Food Production

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Abstract

The manual dough-forming process remains a productivity constraint in small-scale milk pie production due to repetitive pressing activities and high dependence on operator performance. This work aimed to design, develop, and evaluate a semi-automatic milk pie dough-forming machine to improve production capacity and labor productivity in small and medium-sized enterprises (SMEs). The machine development involved user-need identification, design specification, conceptual and detailed design, material and component selection, manufacturing, assembly, and performance testing. The developed machine had overall dimensions of 550 × 500 × 850 mm and was powered by a 0.5 HP electric motor. A single forming station with a mold diameter of 70 mm and a depth of 20 mm was employed. Machine performance was evaluated by comparing the production capacity and labor productivity of manual and semi-automatic forming processes. The results showed that the machine increased the forming capacity from 200 to 650 pies/h, corresponding to a 225% improvement or 3.25 times the manual process capacity. The number of workers required for the forming process decreased from three to one, increasing labor productivity from 66.67 to 650 pies/person/h, equivalent to an 875% improvement. The substantial increase in throughput was primarily attributed to the transfer of repetitive pressing activities from human operators to the motor-driven forming mechanism. These results demonstrate that targeted mechanization of the dough-forming stage can significantly improve production capacity and labor utilization in small-scale milk pie production. Further evaluation of product dimensional uniformity, energy consumption, hygienic design, and long-term operational reliability is required to provide a more comprehensive assessment of machine performance.

Keywords: Dough-forming machine; Labor productivity; Mechanization; Milk pie; Production capacity; SMEs

1. Introduction

The food processing industry faces increasing demands to improve production capacity, process efficiency, and more effective resource utilization. These challenges are especially critical for micro, small, and medium enterprises (MSMEs), a substantial share of whose production processes still rely on manual activities [1], [2]. In the micro- and small-scale food processing sector, capital and labor are factors that strongly influence production efficiency, so that the choice of process technology needs to be adapted to the capability and characteristics of the enterprise [3]. More broadly, mechanization enables operations to be performed faster and more effectively and has the potential to increase productivity and improve labor allocation [4]. One food product widely manufactured at the MSME scale is milk pie (*Pie Susu*). This product is characterized by a dough-based shell that is formed to follow the geometry of a mold and combined with a filling before baking [5], [6]. The shape of the milk pie product that is the object of this study is shown in Figure 1. Its production process generally consists of shell dough preparation, dough division, dough forming in the mold, filling, and baking. Among these stages, dough forming is a process carried out repeatedly for every product unit.



Figure 1. Milk pie as the object of the dough-forming process

In the conventional production process, dough is placed in the mold and pressed manually until it follows the contour of the mold surface. The manual forming process applied at the partner MSME is shown in Figure 2. The operator repeatedly places, presses, and shapes the dough for each mold. This repetitive manual activity increases the dependence of process performance on the operator's rhythm and physical capability. Rosiani *et al.* [7] showed that food processing industries still relying on manual labor face ergonomic challenges in the form of repetitive movements, prolonged static postures, and workload at production stations. Similar findings also indicate that work-related musculoskeletal disorders can affect workers' range of motion and

productivity in the food production industry [8]. A systematic review in the food industry further confirms that repeated manual handling can reduce work productivity if not accompanied by improvements in workstation design [9].

Based on observations of the partner's production process, manual forming can produce approximately 200 pies/h and requires three workers. This condition, manual forming with heavy operator involvement, was identified as the main problem in the initial production process. Under these conditions, labor productivity at the forming stage reached only about 66.67 pies/person/h. When production demand increases, raising capacity by adding workers can increase resource requirements without necessarily producing a proportional gain in efficiency. In micro- and small-scale food processing enterprises, the relationship between labor use, capital, and production efficiency is an important factor in developing business capacity [3]. Studies on scale-appropriate mechanization in the agricultural sector show that applying technology suited to user conditions can significantly increase productivity compared with manual processes [10].

Mechanization is one approach that can be applied to reduce the limitations of manual processes. The principle of mechanization is to transfer part of the force and repetitive-motion requirements from humans to a power-driven system. FAO [4] explains that motorized mechanization can increase productivity, reduce physical workload, and enable more efficient labor allocation. In food product forming processes, mechanical systems can also be directed at specific activities that previously required repetitive manual movement. Automation and mechanization are most effective when applied to resolve or improve a particular process need, rather than merely increasing the technological complexity of the entire production system [11].

In the dough-forming process, a forming mechanism can be used to generate repeated pressing motion so that the operator no longer functions as the main source of force. In the manual process shown in Figure 2, forming speed is influenced by the operator's ability to place and press the dough. When this activity is carried out continuously, changes in work rhythm can affect the cycle time and the number of products produced. The use of a mechanical drive system allows the operator's function to shift from performing repetitive physical activity to controlling the process and handling material. This shift from repetitive physical labor toward supervisory and control activity is one of the important consequences of applying automation to a work system [12].

However, the application of production technology in small-scale food industries has different requirements compared with large-capacity industries. Systems with high complexity and cost are not necessarily suitable for small-scale production environments. Machines for small- and medium-scale food processing need to be developed according to the scale of the process and the characteristics of the resulting product [13]. The development of a dough-mixing machine for small industry, for example, shows that a design tailored to the user's capacity needs can increase process capacity compared with manual methods [14]. This condition demonstrates the importance of developing machines oriented toward the user's actual process needs.

Besides capacity and ease of operation, food processing machines need to consider design characteristics that support process safety and cleanliness. Equipment design plays an important role in preventing residue retention and affects how easily contaminants can be removed during cleaning [15]. Musiari *et al.* [16] also emphasize that



Figure 2. Manual dough-forming process for milk pie: (a) placement and shaping of the dough in the mold and (b) pressing of the dough by the operator

hygienic design principles need to be integrated into the development of food processing machines and equipment through the application of design rules suited to process characteristics. Therefore, material selection for product-contact areas, component geometry, and ease of cleaning need to be considered from the design stage onward.

Various food-machine development efforts show that mechanization can be focused on a specific unit operation to improve process performance. Saputra *et al.* [14] developed a dough-mixing machine to

increase process capacity and consistency in small-scale production. Similar studies on the design of small-scale dough-mixing machines also show that the calculation of mechanical components and the selection of an appropriate drive motor are important parts of designing MSME-scale food processing machines [17], [18]. At a higher level of automation, the integration of robotic systems in food processing is also directed toward increasing productivity and reducing dependence on labor for certain operations [19]. Nevertheless, highly automated technology is not always the most suitable choice for small-scale production environments because of the investment requirements and the complexity of implementation.

Based on these developments, there is a need to develop a production mechanism specifically directed at the process bottleneck and adapted to the characteristics of MSME production. In the milk pie production examined in this study, the dough-forming process is still performed manually and requires three operators to produce approximately 200 pies/h. The absence of a forming mechanism adapted to the geometry of the milk pie mold and the partner's operational conditions became the basis for developing the semi-automatic machine. In contrast to an approach that automates the entire production line, this development is focused specifically on mechanizing the application of pressing force during dough forming.

The novelty of this development lies in the application of a semi-automatic forming mechanism adapted to the geometry of the milk pie mold and the production needs of MSME scale. The machine was developed as a mechanization unit for the forming stage while dough handling is still performed by the operator. This approach allows the machine construction to remain relatively simple, while the repetitive pressing activity is transferred to an electric motor-powered mechanism. Performance evaluation was focused on the change in forming capacity and labor productivity compared with the manual process.

Based on this problem, this study aims to design, build, and evaluate the performance of a semi-automatic milk pie dough-forming machine. The evaluation was carried out based on forming capacity and labor productivity before and after the machine was implemented. The development results are expected to provide a technical basis for applying simple mechanization in MSME-scale food production processes and to support the development of machines suited to users' capacity needs and process characteristics.

2. Methods

The semi-automatic milk pie dough-forming machine was developed through an engineering design approach combined with experimental testing. The development process was based on the actual problem identified in the manual dough-forming process at the partner MSME. The stages carried out included needs identification, design specification, concept development, detailed design and component selection, manufacturing and assembly, and machine performance testing. The test results were then evaluated to determine whether machine performance met the established production requirements. The overall machine development flow is shown in Figure 3. The development process used an iterative approach. If the test results did not meet the specified performance requirements, an evaluation was carried out to identify the parts requiring improvement. The evaluation results were then used as the basis for refining the design or components before the machine was tested again.

2.1. Machine development stages

The initial stage of development was carried out through a survey of the milk pie production process at the partner MSME. The observation focused on the dough-forming stage, which was still performed manually as shown in Figure 2. The identification covered the condition of the forming process, actual capacity, the number of workers involved, and the operator's work pattern. The manual process produced approximately 200 pies/h and required three workers. This condition was used as the baseline for establishing the machine's performance requirements.

The machine's initial specifications were determined by considering the required production capacity, product size, mold dimensions, power source, cost constraints, and ease of operation. The machine was designed to replace the manual application of pressing force, while dough placement and product handling remained the operator's responsibility. Based on this work configuration, the machine was developed using a semi-automatic system.

The dimensions of the forming component were adapted to the milk pie mold used by the partner. The mold has a diameter of 70 mm and a depth of 20 mm. An electric power source was selected to drive the forming mechanism, while the work-area configuration was designed so that the machine could be operated by a single person. Simplicity of construction and ease of maintenance were also used as the main constraints in the design development process.

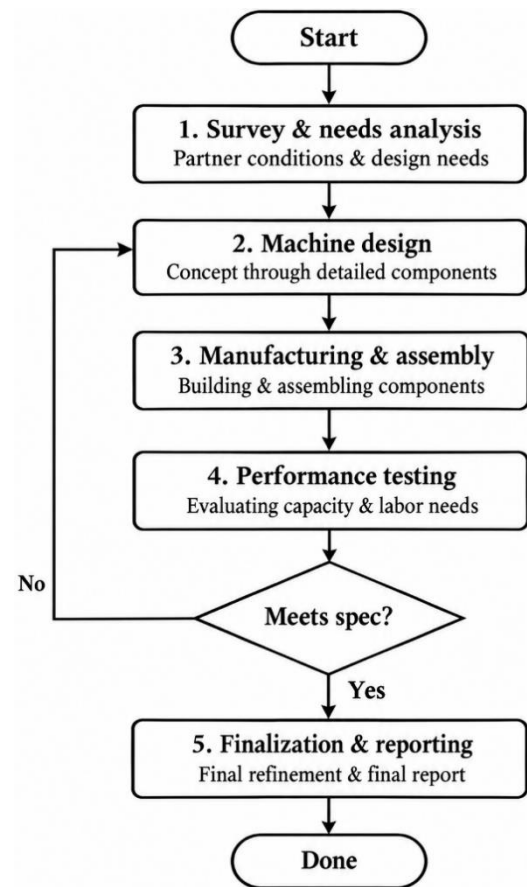


Figure 3. Flow diagram of the development and testing of the semi-automatic milk pie dough-forming machine

2.2. Design criteria

Concept development was carried out by determining the configuration of the drive system, the forming mechanism, and the component layout. The working principle developed was to convert mechanical energy from the electric motor into motion at the forming component, so that the dough-pressing process could be carried out without direct force application by the operator. A 0.5 HP electric motor was used as the main power source. This approach to determining drive-component specifications is consistent with common practice in the design of other small-scale machines, such as the development of hydraulic press machines [20] and the optimization of chain-sprocket transmission components [21], which emphasize the importance of force analysis and component capacity in quantitatively determining drive specifications. Motion from the motor is transmitted through a mechanical system to the forming component. This mechanism generates a working motion at the mold to apply pressure to the dough until it follows the geometry of the milk pie mold. The machine structure was designed using a vertical configuration. The drive system is placed at the lower part of the structure, while the forming mechanism is located

at the upper part of the machine. This layout was chosen to produce a relatively compact construction and to provide the operator with adequate access to the forming area. The design results in a machine with a length of 550 mm, a width of 500 mm, and a height of 850 mm. The machine uses a single forming station with a mold diameter of 70 mm and a depth of 20 mm. The machine's main specifications are presented in Table 1 and its design is presented in Figure 4.

Table 1. Design specifications of the milk pie dough-forming machine

Parameter	Specification
Machine length	550 mm
Machine width	500 mm
Machine height	850 mm
Electric motor power	0.5 HP
Number of forming stations	1
Mold diameter	70 mm
Mold depth	20 mm
Operating system	Semi-automatic

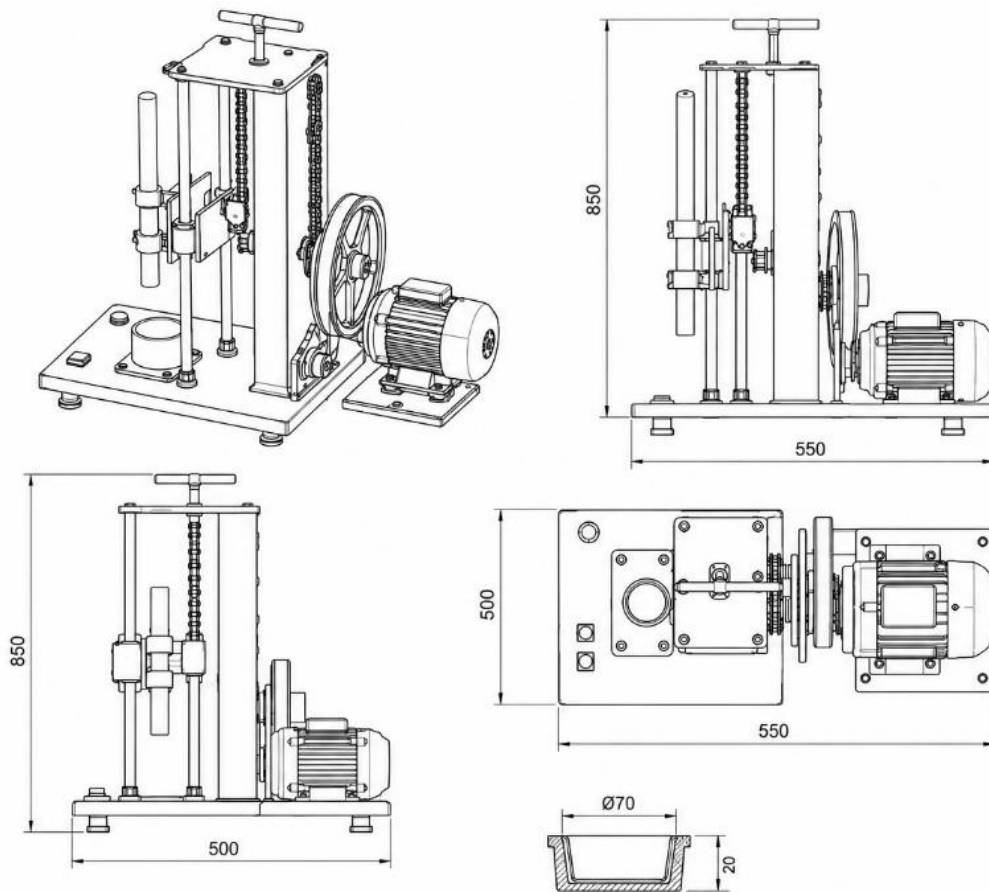


Figure 4.
Design of the semi-automatic milk pie dough-forming machine

2.3. Material and component selection

Material and component selection was based on the function of each part, structural strength requirements, ease of manufacturing, and material availability. The main structure uses steel profile as the frame supporting the drive system and the forming mechanism. This material was chosen to produce a structure capable of maintaining machine stability during the forming process. The materials and components used include steel profile, stainless steel, nylon, shafts, bearings, and an electric motor. Stainless steel is used for components related to the forming area, while bearings are used to support moving components and maintain mechanism motion. Nylon is used in certain parts that require a relatively light material with frictional characteristics suited to the component's function. Standard components were prioritized to simplify replacement and maintenance. This approach was adapted to the machine's intended use in an MSME-scale production environment, so that maintenance can be carried out using relatively simple procedures and tools.

2.4. Manufacturing and assembly

The manufacturing process was carried out based on the dimensions and configuration established at the design stage. The equipment used included welding, lathe, drilling, and grinding machines. Frame fabrication began with cutting the steel profile to the specified dimensions, followed by welding to form the machine's main structure. Mechanical components requiring dimensional precision were produced using turning and drilling processes. After all components were completed, the electric motor, mechanical system, shaft, bearing, and the forming component were installed on the machine frame. The position of each component was adjusted to ensure that the forming mechanism could move along the planned working path. An initial function check was carried out after assembly was completed. The machine was first run without load to observe the function of the drive system and the motion of the forming mechanism. The inspection focused on the smoothness of the forming component's motion and the function of the drive components. Discrepancies found at this stage were corrected through component adjustment before the machine was used to form dough.

2.5. Machine performance testing

Performance testing was carried out by comparing the manual forming process with the forming process using the semi-automatic machine. The parameters evaluated included forming capacity, the number of workers, and labor productivity. The manual forming process was used as the baseline condition for evaluating the change in performance after the machine was implemented.

Forming capacity was determined based on the number of pies that could be formed per unit time and calculated using Eq. (1):

$$Q = \frac{N}{t} \quad (1)$$

where Q is the forming capacity (pies/h), N is the number of pies successfully formed, and t is the forming process time (h).

The percentage increase in capacity after using the machine was calculated using Eq. (2):

$$I_Q = \frac{Q_m - Q_{man}}{Q_{man}} \times 100\% \quad (2)$$

where I_Q is the capacity increase (%), Q_m is the forming capacity using the machine (pies/h), and Q_{man} is the manual forming capacity (pies/h).

Labor productivity was calculated based on forming capacity and the number of operators involved using Eq. (3):

$$P_L = \frac{Q}{L} \quad (3)$$

where P_L is labor productivity (pies/person/h), Q is the forming capacity (pies/h), and L is the number of workers involved.

The percentage increase in labor productivity was calculated using Eq. (4):

$$I_P = \frac{P_{L,m} - P_{L,man}}{P_{L,man}} \times 100\% \quad (4)$$

where I_P is the increase in labor productivity (%), $P_{L,m}$ is labor productivity using the machine, and $P_{L,man}$ is labor productivity in the manual process.

3. Results and Discussion

3.1. Machine development results

The design and manufacturing process produced a semi-automatic milk pie dough-forming machine with a vertical configuration. The prototype machine that was built is shown in [Figure 5](#). The machine has overall dimensions of 550 mm × 500 mm × 850 mm and uses a 0.5 HP electric motor as the drive power source. The forming system uses a single mold with a diameter of 70 mm and a depth of 20 mm. These specifications are consistent with the prototype and the machine's technical data in the initial document. As shown in [Figure 4](#), the machine structure uses a vertical frame with the drive system placed at the bottom. The forming mechanism is located at the top of the structure and forms a single forming work station. This layout results in a relatively compact machine configuration and allows the operator to access the forming area from the front of the machine.

The use of an electric motor as the drive source changes the working principle of forming, which previously relied on the operator's pressing force. In the manual process shown in [Figure 2](#), the operator directly applies force to shape the dough to follow the mold geometry. In the semi-automatic machine, the force-application function is transferred to the machine mechanism, while the operator handles dough placement and system operation. This shift in work function is relevant to food-production-system improvement approaches that seek to reduce repetitive manual activity. [Rosiani et al. \[7\]](#) show that repetitive activity and poor ergonomic conditions in food production processes can contribute to process waste and reduce work-system performance.

This configuration shows that mechanization was not applied to the entire milk pie production line. Dough preparation, ingredient placement, filling, and subsequent processes still involve human labor. Mechanization was

specifically directed at the repetitive dough-pressing activity. This approach is consistent with the machine development objective, namely to reduce dependence on manual force application without excessively increasing system complexity.

3.2. Production capacity

The test results show an increase in capacity after the manual forming process was replaced with the semi-automatic machine. A comparison of the capacity and labor requirements of the two methods is presented in Table 2. The original test data show a capacity of 200 pies/h for the manual method and 650 pies/h using the machine. The number of workers required for the same process decreased from three to one. Using the machine increased the forming capacity by $I_Q = (650 - 200) / 200 \times 100\% = 225\%$. Thus, the process capacity increased by 225%, or 3.25 times the manual forming capacity. These results show that mechanizing a single process stage can produce a substantial change in *throughput* without requiring automation of the entire production line.

The increase in capacity can be explained by the change in activity within a single forming cycle. In the manual method, the operator must place the dough and apply pressing force directly for every product. This activity is performed repeatedly, so forming speed is heavily influenced by the operator's work rhythm and physical capability. Repetitive activity is a common ergonomic issue found in manual food production processes. Ergonomic evaluations in the food production industry show that manual work activity can create a risk of musculoskeletal disorders and requires improvement of workstation conditions [8]. These findings also show that increasing capacity does not always require adding more forming stations. The developed machine still uses a single mold, yet it is able to produce higher capacity than the manual process. This indicates that forming cycle time is one of the important parameters in the productivity of the dough-forming process.

Table 2. Comparison of forming process performance

Forming method	Production capacity (pies/h)	Labor (persons)	Labor productivity (pies/person/h)
Manual	200	3	66.67
Semi-automatic machine	650	1	650

3.3. Labor productivity

In addition to increasing forming capacity, using the machine changed the labor requirements. The manual process required three people to produce 200 pies/h. Labor productivity under these conditions is $P_{L,man} = 200/3 = 66.67$ pies/person/h. After the semi-automatic machine was implemented, the forming process could be carried out by a single operator with a capacity of 650 pies/h. Labor productivity becomes $P_{L,m} = 650$ pie/orang/jam. Based on Equation (4), the increase in labor productivity is $I_p = (650 - 66.67) / 66.67 \times 100\% = 875\%$. Thus, labor productivity increased by 875%, or to approximately 9.75 times the productivity of the manual method. This increase is a consequence of two simultaneous changes, namely the rise in forming capacity and the decrease in the number of operators.

In the manual process, three workers were directly involved in the forming activity to maintain a capacity of 200 pies/h. In contrast, the machine mechanism allows a single operator to handle the process at a higher capacity. This shows that using the machine changes the function of human labor from a source of mechanical force to a process controller and material handler. In the context of MSME-scale production, reducing the number of operators at one process stage does not always mean an overall reduction in the workforce. The two people previously involved in forming can be reallocated to other production stages, such as dough preparation, filling,



Figure 5. Prototype of the semi-automatic milk pie dough-forming machine

baking, or packaging. This redistribution of labor has the potential to improve the capacity balance across processes within the overall production line.

However, an increase in capacity at the forming stage can also create a new bottleneck at the subsequent process. A forming capacity of 650 pies/h must be matched by the capability of the filling and baking processes to handle the increased product flow. If the capacity of the subsequent process remains below 650 pies/h, an accumulation of intermediate product may occur. Bottleneck identification studies in food manufacturing have shown that relieving the constraint at one stage shifts attention to the remaining stages, so that line-level productivity gains depend on balancing the entire production flow [22]. Therefore, implementing the machine needs to be followed by an evaluation of the overall production line balance.

3.4. Design implications for MSME-scale production

The developed machine shows that mechanization with a relatively simple system can improve productivity in small-scale food production processes. The use of a 0.5 HP electric motor and a single forming station produces a capacity of 650 pies/h. From a design perspective, this configuration shows the potential for applying a relatively compact machine in an MSME production environment. Nevertheless, the results of this study are still limited to the evaluation of production capacity and labor productivity. The claim regarding improved product dimensional uniformity cannot yet be evaluated quantitatively because testing of the diameter, thickness, depth, and mass of the product has not been carried out. Therefore, further research needs to compare the geometric and mass variation of products from manual and machine forming using statistical parameters such as standard deviation and the *coefficient of variation*.

An evaluation of energy consumption is also needed to determine the machine's *specific energy consumption* in units of energy per product. This parameter is important for assessing whether the increase in production capacity is also accompanied by adequate energy efficiency. In addition, because the machine is used for a food application, evaluation of the material in parts that come into direct contact with the dough, ease of cleaning, potential material-retention areas, and design hygiene aspects need to be part of the next stage of development. Long-term testing is also required to evaluate the reliability of the forming mechanism. An instantaneous capacity of 650 pies/h does not by itself demonstrate the machine's ability to sustain performance over a full production cycle. Continuous testing can be used to identify changes in cycle time, increases in drive-component temperature, mechanism wear, and maintenance needs. Considering these limitations, the results of this study provide initial evidence that mechanizing the forming process is an effective approach for improving milk pie production productivity. Further development needs to be directed toward a multidimensional evaluation covering capacity, product quality, energy, reliability, safety, and machine hygiene.

3.5. Limitations

The forming capacity of 650 pies/h produced by a single forming station corresponds to an average cycle time of approximately 5.54 seconds per pie (3600 seconds divided by 650). This value is arithmetically consistent with Eq. (1); however, this study has not included a kinematic analysis of the mechanism (the velocity and acceleration of the forming component, the transmission ratio, and the actual pressing force acting on the dough) that could technically explain how this cycle time is achieved by a 0.5 HP motor. Calculations of pressing force, motor torque, transmission ratio, and structural component strength analysis have not been carried out at this stage, so the selection of the 0.5 HP motor specification is not yet explicitly supported by engineering calculation justification. Such engineering calculations are an important part that needs to be completed in further research to verify the match between the motor's force capacity and the workload of the forming mechanism.

The capacity and productivity data reported in Table 2 were obtained from a single series of tests and did not involve replication or repeated measurement. The variability of cycle time between tests, the standard deviation, and the level of consistency of results across repetitions cannot yet be reported. Testing with an adequate number of replications is needed in further research so that the significance and consistency of the performance improvement can be evaluated statistically. Operator safety and food safety aspects of the current design have also not been evaluated comprehensively. Moving transmission components such as the chain, pulley, and belt on the prototype are not yet equipped with a protective safety cover or an *emergency stop* button, which could create a pinch-point risk for the operator in the forming area. Risk-assessment approaches based on machine safety design principles have

been widely used to identify and reduce such hazards at the design stage [23], but this evaluation has not yet been applied to the machine developed in this study. In addition, although stainless steel is used for components in direct contact with the dough, the mitigation of contamination risk from lubricant, iron filings, or paint flakes originating from structural and transmission components around the forming area has not been analyzed. Both aspects need to become priorities for design revision before the machine is applied more broadly in a food production environment, including the addition of mechanical guards, an emergency-stop mechanism, and an evaluation of potential cross-contamination pathways.

4. Conclusion

A semi-automatic milk pie dough-forming machine has been designed and built with dimensions of 550 × 500 × 850 mm, using a 0.5 HP electric motor and a mold with a diameter of 70 mm and a depth of 20 mm. Using the machine increased the forming capacity from 200 to 650 pies/h, an improvement of 225% compared with the manual method. At the same time, labor requirements decreased from three to one person, so labor productivity increased from 66.67 to 650 pies/person/h, an improvement of 875%. These results show that mechanizing the forming stage is able to increase *throughput* and labor efficiency in MSME-scale milk pie production. However, this study is still limited to the evaluation of capacity and labor productivity. Further testing of product dimensional and mass uniformity, energy consumption, long-term reliability, and design hygiene aspects is required to provide a more comprehensive evaluation of machine performance. This study also did not include machine engineering calculations (pressing force, motor torque, and transmission analysis), replicated testing, or an evaluation of operator safety with respect to the still-exposed transmission components, so these aspects need to become the main focus of the next development stage before the machine is applied more broadly.

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Conflict of Interest - The authors declare that there are no conflicts of interest.

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References

- [1] L. I. Wijaya, Z. Zunairoh, M. Izharuddin, and A. Rianawati, "Scope of E-Commerce use, innovation capability, and performance: Food sector MSMEs in Indonesia," *Journal of Open Innovation: Technology, Market, and Complexity*, vol. 11, no. 1, p. 100459, 2025, doi: 10.1016/j.joitmc.2024.100459.
- [2] I. Masudin, I. D. Lestari, A. Khoidir, and D. P. Restuputri, "Sustainable Procurement Barriers in Indonesian Food Manufacturing SMEs: An ISM–Fuzzy MICMAC Analysis," 2025. doi: 10.3390/logistics9040175.
- [3] F. S. Islami, S. N. Sarfiah, L. R. Indrawati, W. Juliprijanto, and Y. Septiani, "Measuring inefficiency of MSEs in the food processing sector," *Jurnal Ekonomi dan Bisnis*, vol. 26, no. 1 SE-Articles, pp. 269–288, May 2023, doi: 10.24914/jeb.v26i1.5467.
- [4] FAO, "The State of Food and Agriculture 2022. Leveraging automation in agriculture for transforming agrifood systems.," FAO, Rome, 2022. doi: 10.4060/cb9479en.
- [5] M. A. N. Fauzi, Y. F. Rohmah, K. Khoiriyah, A. Machrus, and N. Nuruddin, "Strategi UMKM CV. Najwa dalam Meningkatkan Daya Saing Pemasaran Pie Susu Khas Bali," *Dalwa Islamic Economic Studies: Jurnal Ekonomi Syariah*, vol. 3, no. 2, pp. 114–127, 2024, doi: 10.38073/dies.v3i2.2462.
- [6] F. Birtha and A. Sabet, "Milk Pie Production Management System in The MSME (UMKM) Sector in Denpasar (Case Study : UMKM CV. NAJWA)," *ProBisnis : Jurnal Manajemen*, vol. 15, no. 2, pp. 91–100, 2024.
- [7] T. Y. Rosiani, M.-H. Li, and D. Rahmasari, "An Integrated Framework for Ergonomic Performance Assessment in Food Manufacturing: A Case Study Using Ergo-VSM, AHP, and TLS," *Jurnal Optimasi Sistem*

- Industri*, vol. 24, no. 1 SE-Articles, pp. 84–101, Jun. 2025, doi: 10.25077/josi.v24.n1.p84-101.2025.
- [8] H. Mohd Fazi, N. M. Z. Nik Mohamed, M. F. F. Ab Rashid, and A. N. Mohd Rose, “Ergonomics study for workers at food production industry,” in *MATEC web of conferences*, EDP Sciences, 2017, p. 1003. doi: 10.1051/mateconf/20179001003.
 - [9] J. Ariyanto, S. Palutturi, S. S. Russeng, B. Warsinggih, and L. Rosyanti, “Control of the Risk of Musculoskeletal Disorders in the Food Industry : Systematic Review Department of Health Administration and Policy , Faculty of Public Health , Department of Occupational Safety and Health , Faculty of Public Health , Hasanuddin Poli,” *Annals of the Romanian Society for Cell Biology*, vol. 25, no. 1, 2021.
 - [10] G. P. Paudel, D. B. KC, D. B. Rahut, S. E. Justice, and A. J. McDonald, “Scale-appropriate mechanization impacts on productivity among smallholders: Evidence from rice systems in the mid-hills of Nepal,” *Land Use Policy*, vol. 85, pp. 104–113, 2019, doi: 10.1016/j.landusepol.2019.03.030.
 - [11] Y. Kim and S. Kim, “Automation and Optimization of Food Process Using CNN and Six-Axis Robotic Arm,” 2024. doi: 10.3390/foods13233826.
 - [12] V. Marinoudi *et al.*, “Adapting to the Agricultural Labor Market Shaped by Robotization,” 2024. doi: 10.3390/su16167061.
 - [13] J. Grochowicz and R. Nadulski, “Small-Scale Technologies and Minimally Processed Food – An Overview of Accessible Technical Equipment and Conditions of Implementation on the Example of Poland,” *Polish Journal of Food and Nutrition Sciences*, vol. 57, no. 2A, pp. 67–70, 2007, [Online]. Available: <https://journal.pan.olsztyn.pl/>
 - [14] M. A. C. Saputra, Mulyadi, A. Fahrudin, and E. Widodo, “Dough Mixer Machine Design Increases Cracker Production Capacity: Desain Mesin Pengaduk Adonan Meningkatkan Kapasitas Produksi Kerupuk,” *Indonesian Journal of Innovation Studies*, vol. 26, no. 4 SE-Innovation in Mechanical Engineering, p. 10.21070/ijins.v26i4.2126, May 2026, doi: 10.21070/ijins.v26i4.2126.
 - [15] C. Faille, C. Cunault, T. Dubois, and T. Bénézech, “Hygienic design of food processing lines to mitigate the risk of bacterial food contamination with respect to environmental concerns,” *Innovative Food Science & Emerging Technologies*, vol. 46, pp. 65–73, 2018, doi: 10.1016/j.ifset.2017.10.002.
 - [16] F. Musiari, F. Moroni, A. Pirondi, and C. Favi, “Towards computer-aided hygienic design: Definition of a knowledge-based system for food processing equipment,” *Journal of Food Engineering*, vol. 363, p. 111776, 2024, doi: 10.1016/j.jfoodeng.2023.111776.
 - [17] B. E. Okafor, “Design of Power Driven Dough Mixing Machine,” *International Journal of Engineering and Technology*, vol. 5, no. 2, pp. 76–79, 2015.
 - [18] A. Rachmandani and Mulyadi, “Compact Bread Dough Mixer Achieved Three Kilogram Capacity,” *Indonesian Journal of Innovation Studies*, vol. 26, no. 4 SE-Innovation in Mechanical Engineering, p. 10.21070/ijins.v26i4.2136, May 2026, doi: 10.21070/ijins.v26i4.2136.
 - [19] S. Baek, S. E. Oh, S. H. Lee, and K. H. Kwon, “A Simulation-Based Approach for Evaluating the Effectiveness of Robotic Automation Systems in HMR Product Loading,” 2024. doi: 10.3390/foods13193121.
 - [20] F. Adesina, T. I. Mohammed, and O. T. Ojo, “Design and Fabrication of a Manually Operated Hydraulic Press,” *Open Access Library Journal*, vol. 5, no. e4522, pp. 1–10, 2018, doi: 10.4236/oalib.1104522.
 - [21] P. Nikam and R. Tanpure, “Design Optimization Of Chain Sprocket Using Finite Element Analysis,” *International Journal of Engineering Research and Application*, vol. 6, no. 9, pp. 66–69, 2016.
 - [22] S. M. Javadi, S. J. Sadjadi, and A. Makui, “Identification and fixing bottlenecks of a food manufacturing system using a simulation approach,” *Scientific Reports*, vol. 13, no. 1, p. 11786, 2023, doi: 10.1038/s41598-023-39025-5.
 - [23] F. Gauthier, Y. Chinniah, D. Burlet-Vienney, B. Aucourt, and S. Larouche, “Risk assessment in safety of machinery: Impact of construction flaws in risk estimation parameters,” *Safety Science*, vol. 109, pp. 421–433, 2018, doi: 10.1016/j.ssci.2018.06.024.