



## ERGONOMICS THERMAL ENGINEERING APPROACH IN DESIGNING TRADITIONAL DRYER WITH RICE HUSK ENERGY FOR SMALL-SCALE RENGGINANG PRODUCTION

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### ABSTRACT

Drying is useful for extending the shelf life of a food product by preventing spoilage, making it a crucial step in the *Rengginang* production process to reduce the water content to a safe level. Traditional drying methods, which rely on sunlight, have several limitations, such as dependence on weather, long processing times, and the risk of contamination. This study aims to evaluate the effectiveness of drying rice crackers using thermal energy from rice husks from a technical and ergonomic perspective. The study was conducted to design a dryer using worker anthropometric data and two 360-minute drying scenarios: one using a rice husk-based dryer and one using direct solar drying. The results show that the height of the top and bottom shelves in the drying room is 1285.39 mm and 617.64 mm, based on anthropometric data of standing eye height and gripping hand height. The maximum height of the control device and the height of the door handle are 1649.01 mm and 876.98 mm, based on anthropometric data of standing hand reach and elbow height. The dimensions of the shelves for placing *Rengginang* have a length and width of 711.96 mm and 525.49 mm, respectively, based on anthropometric data of elbow reach and front reach of the gripping hand. The use of a rice husk energy dryer resulted in an average drying temperature of 69.06°C with a range of 51.29-81.90°C, and the initial moisture content of *Rengginang* of 48.27% was successfully reduced to 8.78%. When dried directly in the sun, the moisture content only dropped to 29.21%. This difference indicates a significant influence of technical conditions on drying performance, such as heat distribution and air ventilation. From an ergonomics perspective, drying efficiency contributes to reduced work duration, heat exposure, and worker physical strain. Optimal drying can reduce the risk of musculoskeletal disorders and improve work comfort. Ergonomics thermal engineering results in effective utilization of rice husk energy, including technical aspects and the design of tools and work processes that are appropriate for worker posture.



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### I. INTRODUCTION

Traditional food, as a small business, plays a vital role in supporting the rural economy in Indonesia, particularly in Lombok. One popular product is *Rengginang*, a traditional snack made from sticky rice that requires a drying process as a crucial step in its production. In general, the drying process for *Rengginang* is still traditionally carried out by drying it directly in the sun. This method is highly dependent on weather conditions and takes a long time. It also carries the risk of contamination and inconsistent product quality. Direct sun drying carried out in open areas causes losses such as insect infection, uncontrolled and long drying, dust and dirt contamination, and food is susceptible to microbiological contamination by fungi and pathogens as a result of unhygienic conditions in open environments [1], [2].

*Rengginang*, as a wet food, is also susceptible to contamination by dust, dirt, and microbiological agents such as mold if left in the open for too long. *Rengginang* are traditional rice crackers made from coarsely ground glutinous rice, dried, and then fried until crispy. Although Lombok is located in a tropical region with almost constant sunshine, the temperature is not optimal for the drying process. This is indicated by the long drying time, which automatically stops when the weather is cloudy or rainy. Direct sunlight results in an average drying temperature of 29.44°C [3]. On the other hand, agricultural waste such as rice husks has significant potential as a renewable alternative energy source.

## II. THEORETICAL REFERENCE

Lombok Island is an agricultural region where most farmers grow rice as a staple crop. For example, in 2024, according to data from the Central Statistics Agency (BPS), rice production reached 785,918 tons of dry milled grain on Lombok Island, one of Indonesia's agricultural regions [4]. The by-product of processing rice is 20% in the form of rice husks [5], [6]. Theoretically, the potential for rice husks on Lombok Island for 2024 is 157,184 tons [7]. Improper processing of rice husks, which are the main by-product of rice production, causes environmental impacts such as solid waste [8]. The calorific value of rice husk from several research results which have a calorific value equivalent to half the calorific value of coal includes 11-15.3 MJ/kg [9], net calorific value 12-16 MJ/kg [10], 13-19 MJ/kg with an average of 18 MJ/kg [11], heat heating value  $18.14 \pm 0.04$  MJ/kg [12]. Rice residue in the form of rice husk and rice straw is used as biofuel to supplement or replace fossil fuels. It has an acceptable calorific value, good thermal characteristics, and low gas emissions in both oxidizing and inert atmospheres, making it a sustainable biomass option for economic and environmental growth [12], [13].

The use of rice husk biomass can be considered as a substitute for fossil fuels, the demand for which is increasing, and the price is increasing, especially for rural communities with small-scale agriculture. Fuel demand is influenced by fuel prices and population growth, which impact economic stability and environmental protection [14]. Rice husks are a biomass waste abundant in agricultural areas, but their use as an energy source for small businesses remains very limited. Proper processing of rice husks can produce an efficient and environmentally friendly drying fuel. Designing a rice husk-based dryer requires consideration of technical and thermal aspects as well as the comfort and safety of business operators. These technical and thermal aspects can be addressed through an energy conversion process using a heat exchanger to convert ambient air into heat. The use of a heat exchanger with rice husk energy can produce a drying temperature between 73 and 119°C, and a mixture of rice husk energy and solar energy produces an average combustion chamber temperature of 347.3°C [15], [16].

Rice husk is suitable for energy use as biomass fuel because of its high silica content, and is superior to rice straw [17]. A heat exchanger can increase the temperature during the drying process by converting biomass energy into thermal energy. A heat exchanger implements the heat transfer process between two fluids at different temperatures separated by a wall without mixing. It can also be used to recover waste heat to reduce the need for additional heating [18-20]. Occupational comfort and safety aspects influence the productivity levels of workers involved in outdoor work due to heat exposure. High heat exposure results in low productivity for outdoor workers, particularly in tropical climates. 60% of workers experience a decrease in productivity when exposed to high heat (WBGT >28°C or temperature >35°C), 30% in indoor or outdoor industries during heat stress conditions, with a decrease in productivity of 2.6% for each degree above the wet bulb temperature of 24°C (WBGT), and a significant economic burden due to work-related heat stress [21-23].

Outdoor workers have a number of risk factors, namely heat stress and heat-related conditions, which affect health, well-being, and productivity, as well as work-related injuries, reduced psychomotor performance, loss of concentration, reduced alertness, loss of coordination, fatigue, and affect productivity and sectoral economies, especially in areas that are highly susceptible to heat [24-27]. Therefore, an ergonomics thermal engineering approach is needed, namely a multidisciplinary approach that integrates the principles of energy efficiency (thermal) and operator comfort and safety (ergonomics) in tool design. Ergonomics assessment is important to increase productivity and reduce risks in physical work [28]. Current ergonomics interventions have had an impact on reducing musculoskeletal disorders (MSDs) complaints widely [29]. The decline in performance that influences the decline in work productivity is the impact of various complaints, both physical and psychological [30].

The Occupational Safety and Health Administration (OSHA) provides recommendations regarding ergonomic measures to prevent sources of disease, namely (1) engineering, such as the design of work tools and work stations; (2) management engineering, such as work organization. These recommendations reduce musculoskeletal disorders in workers to avoid the risk of work injuries [31]. Ergonomics thermal engineering, such as the use of cross ventilation, shade nets, and tool design at optimal heights, has been proven to reduce heat loads and the risk of worker fatigue [32]. Thermal comfort for outdoor applications has more than 20 indices, human psychological states, and other parameters, but most of the models are based on physiological and psychological levels [33]. The combination of rice husk-fueled dryer design and worker-oriented design is known as ergonomics thermal engineering. This approach is expected to produce a dryer design that is not only energy efficient and uses renewable fuels but also ergonomic in its use. Thus, the application of appropriate technology based on ergonomic thermal engineering can increase productivity, product quality, and the sustainability of small businesses such as *Rengginang* production at the household level.

## III. MATERIALS AND METHODS

The study was conducted using an ergonomics thermal engineering approach. The ergonomics approach was implemented through the participation of workers from small *Rengginang* (rice crackers) businesses who dry the product. The study used worker anthropometric data, a Nordic Body Map (NBM) questionnaire, percentile tables, and materials such as rice husks, *Rengginang* (rice crackers), drying equipment, a drying device with a vertical shelf-shaped drying chamber, and two biomass furnaces. The dryer design was based on user participation, with dimensions based on worker anthropometric data and readily available dryer materials. This ensured the dryer was appropriate for the needs of small *Rengginang* businesses.

The dryer was designed for rice husk energy, and the dryer dimensions were based on workers' anthropometric data. Female workers were first subjectively assessed for musculoskeletal complaints about their work posture during the *Rengginang* drying process.

Musculoskeletal complaints were measured using the Nordic Body Map (NBM) questionnaire. The Nordic Body Map (NBM) measures and identifies muscle and skeletal complaints in various parts of the worker's body due to their work posture. This tool is handy in the initial assessment of ergonomics risks, especially in work environments that require physical activity, such as lifting, bending, prolonged sitting, or repetitive movements. This questionnaire is standard and widely used in ergonomics research due to its low cost, worker involvement, and ease of data collection.

The Nordic Body Map questionnaire was used to identify MSDs symptoms in workers related to ergonomics risks, measuring the risk of injury in human-machine interaction activities [34], [35]. The ergonomic approach was limited to dryer design, while the thermal approach was carried out through direct sunlight drying tests and a drying device. *Rengginang* samples weighing approximately 5 kilograms were used for testing in the drying chamber, and approximately 1 kilogram for testing in direct sunlight. Ergonomics analysis was conducted by comparing them with related research results, while thermal analysis was performed by measuring the ambient and drying chamber temperatures and moisture content. Temperature measurements in the dryer were performed using a K-type thermocouple and a data logger. The dryer design used in this study is a modification and application of Patents IDS000004448 and IDS000005388 [36], [37].

The measurement of workers' anthropometric data was adjusted to the dryer design's needs. The subjects were 25 female workers taken from one of the traditional *Rengginang* businesses in Mataram, Lombok, Indonesia. Measurements include eye height in a standing position, namely for the height of the top shelf, the height of the hand gripping for the height of the bottom shelf, the height of the hand reach in an upright standing position for the maximum height limit of the control device, the height of the standing elbow for the height of the door handle, the width of the elbow span for the maximum length of the tray, and the front reach of the hand gripping for the maximum width of the tray. Anthropometric data were then calculated using percentile values. In this case, the 5th percentile ensures that all subjects can use the dryer design if implemented in the prototype. The 5th percentile is shown in Equation 1.

$$\text{Percentile 5} = \bar{x} - (1.65 \delta) \quad (1)$$

The 5th percentile is calculated based on the mean value ( $\bar{x}$ ) and standard deviation ( $\delta$ ) from measurement data. Standard deviation ( $\delta$ ) as in Equation 2, where  $x_i$  is the measurement data,  $\bar{x}$  is the mean of the measured data, and  $n$  is the number of measured data.

$$\delta = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}} \quad (2)$$

Dryer testing was conducted to dry *Rengginang* by measuring the ambient temperature, drying chamber temperature, and outlet temperature. The testing time was 360 minutes to avoid over-drying and ensure stable drying results. Furthermore, the traditional drying process for *Rengginang* in the sun can take 6–12 hours, depending on the weather, and a 360-minute test is a realistic representation. The calculation of the %wb (wet basis) moisture content of *Rengginang* uses several equations. The wet moisture content (wb) is calculated based on the total weight.

$$\text{Initial Water Mass} = \text{Initial Material Mass} \times \text{Initial Material Moisture Content} \quad (3)$$

$$\text{Dry Mass} = \text{Initial Material Mass} - \text{Initial Water Mass} \quad (4)$$

$$\text{Final Water Mass} = \text{Final Material Mass} - \text{Dry Mass} \quad (5)$$

$$\text{Final Moisture Content (wb)} = \frac{\text{Final Water Mass}}{\text{Final Material Mass}} \times 100\% \quad (6)$$

In the research, the results of the dryer design have not been tested on humans or workers, only limited to the use of workers' anthropometric data.

#### IV. RESULTS AND DISCUSSIONS

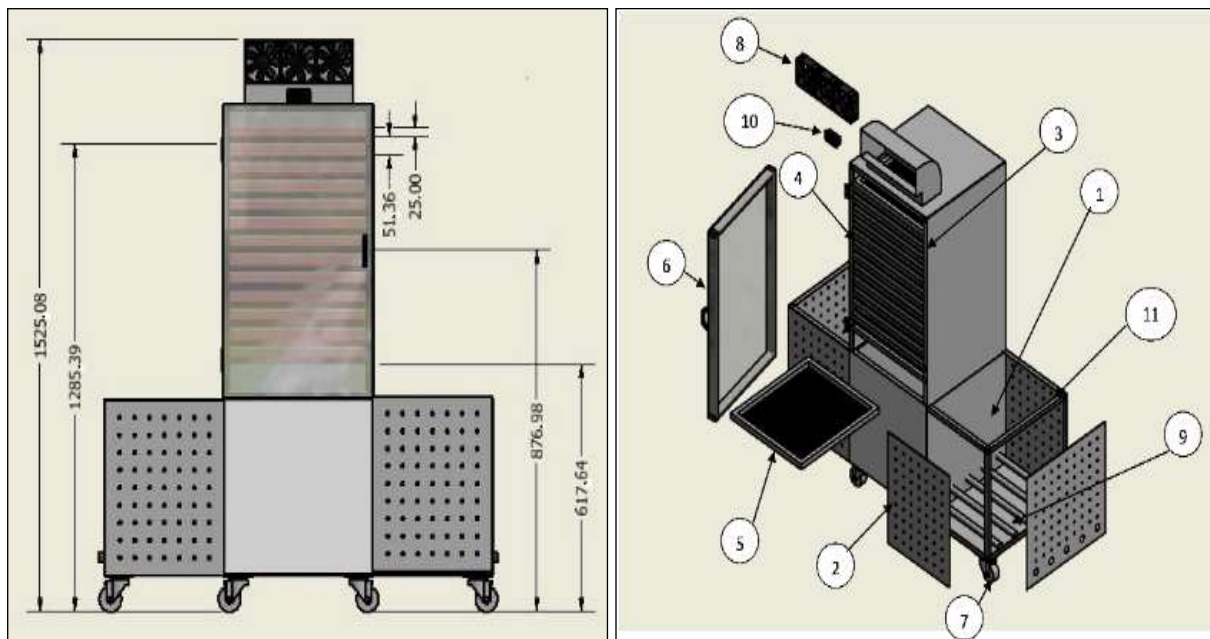
The results of measuring the level of musculoskeletal complaints using the Nordic Body Map questionnaire on several workers who carried out the *Rengginang* drying process found that after work, the average was 55. This total score has a moderate risk level and requires corrective action. The total individual score from the measurement of musculoskeletal complaints using the Nordic Body Map 50-70 has a moderate risk level and requires improvements to the work tools used [30]. Musculoskeletal complaints in workers are caused by unnatural working postures and exposure to the heat of the sun due to work being carried out in open areas during the *Rengginang* drying process, as shown in Figure 1. Figure 1 is based on the guidance of a student's final assignment that has not been published [38]. Figure 1 shows the work process carried out with an unnatural posture.



Figure 1: The worker's posture when drying *Rengginang*.  
Source: [38].

Work processes carried out in unnatural postures can result in musculoskeletal complaints with symptoms including pain in the upper and lower back, neck, shoulders, hands, wrists, elbows, knees and ankles, as well as an increased risk of work injuries [31], [39], [40]. An ergonomics approach to small-scale *Rengginang* production was applied through worker participation, namely the use of anthropometric data. The results of anthropometric data measurements from 25 workers obtained an average standing eye height of 137.732 cm with a standard deviation of 5.572 and a 5th percentile value of 128.539 cm. The average hand grip height was 66.888 cm with a standard deviation of 3.105, and the 5th percentile value was 61.764 cm. The average hand reach height was 177.732 cm with a standard deviation of 7.776, and the 5th percentile value was 164.901 cm. The average standing elbow height was 94.86 cm with a standard deviation of 4.341, and the 5th percentile value was 87.698 cm. The average elbow span width was 75.9 cm with a standard deviation of 2.851, and the 5th percentile value was 71.196 cm.

The average front reach of the grasping hand is 57.90 cm with a standard deviation of 3.241, and the 5th percentile value is 52.549 cm. The application of the 5th percentile from the results of anthropometric data measurements is used as a maximum dimension requirement for the dryer design in this study. The height of the top and bottom shelves in the drying chamber is 1285.39 mm and 617.64 mm, based on anthropometric data of standing eye height and grasping hand height. The maximum height of the control device and the height of the door handle are 1649.01 mm and 876.98 mm, based on anthropometric data of the hand reach height and standing elbow height. The dimensions of the rack, which is used to place the *Rengginang*, have a length and width of 711.96 mm and 525.49 mm, respectively, based on anthropometric data of the elbow reach width and the front reach of the hand gripping. These results are applied to the design of the dryer as presented in Figure 2. Based on the design in Figure 2, the application is in the form of a prototype drying tool with a *Rengginang* drying process as shown in Figure 3.



1. Furnace, 2. Air circulation holes, 3. Drying chamber, 4. Drying shelf limit, 5. Tray, 6. Drying chamber door, 7. Wheel, 8. Exhaust fan, 9. Heat exchanger pipe, 10. Thermostat.

Figure 2: Dryer design with dimensions based on worker anthropometric data, in millimetres (mm).  
Source: [38].

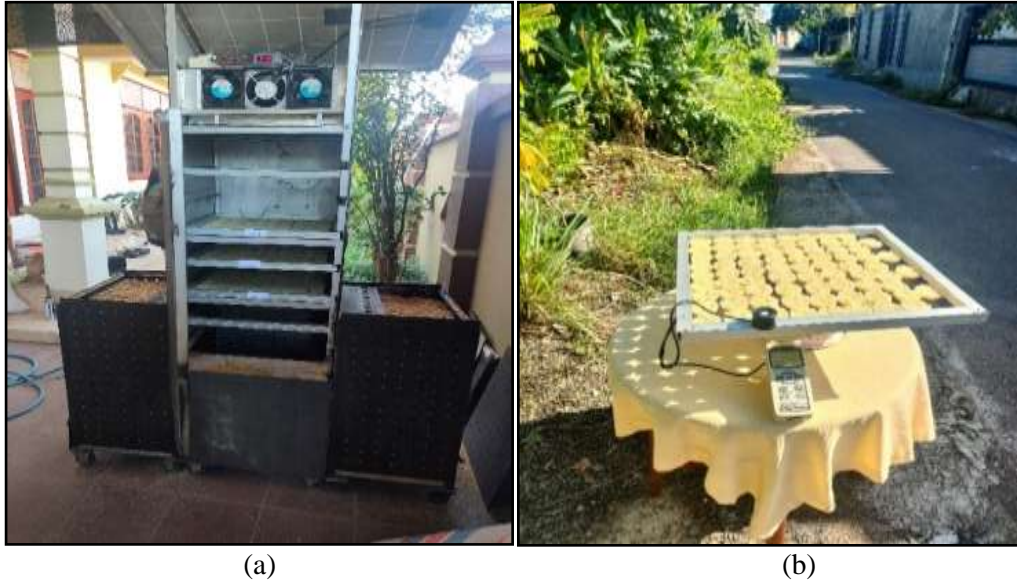


Figure 3: Drying of *Rengginang*: a) rice husk energy dryer, b) direct sunlight.  
Source: Authors, (2026).

The drying process for *Rengginang* using a dryer designed with an ergonomics thermal approach, as shown in Figure 3(a), can be carried out indoors. This ensures workers are not exposed to the sun's heat and allows for a more natural working posture, as seen from the use of vertical racks in the drying room. The energy source uses rice husk biomass. The dryer is also equipped with solar cells to drive a fan, ensuring heat transfer occurs through forced convection. This is in line with the research of Duque-Dussán et al., which shows that hybrid solar dryers that combine solar and mechanical drying principles are equipped with biomass burners and photovoltaic systems, allowing for completely independent drying [41]. A shelf adapted to anthropometric data makes it easier for operators to retrieve/insert trays without bending. Furthermore, the resulting product is more hygienic because the drying process takes place in a closed drying room.

Workers no longer have to monitor the dried product, and it doesn't need to be turned over. Ergonomics interventions through engineering have resulted in a significant reduction in ergonomics risk factors and reduced rates of musculoskeletal disorders among workers [42]. Ergonomics approaches are effective in reducing postural loads and can be seen as an opportunity for farmers to increase attention to health and well-being in farming [43]. Figure 3(b) shows the direct sun-drying process carried out in an open space. This leaves the dried product vulnerable to dust and other dirt, and workers exposed to the sun's heat. Furthermore, the drying temperature is suboptimal because it uses ambient temperature. Figure 4 shows the results of temperature measurements for the *Rengginang* drying process using rice husk energy dryers and direct sunlight.

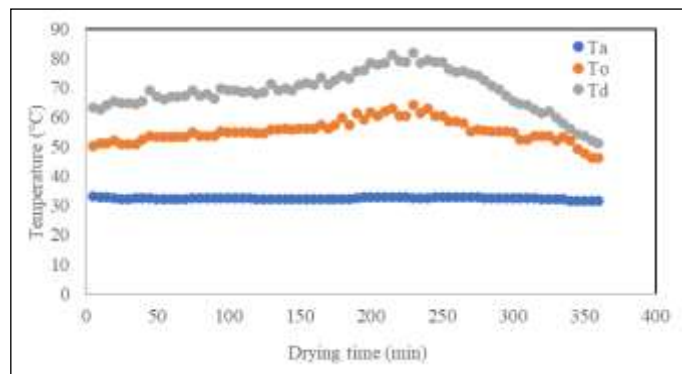


Figure 4: Distribution of drying temperature of *Rengginang* with a dryer and direct sunlight.  
Source: Authors, (2026).

The average ambient temperature ( $T_a$ ) used to dry *Rengginang* was  $32.42^{\circ}\text{C}$ , with a range of  $31.54\text{--}33.04^{\circ}\text{C}$ . Temperature measurements were taken from the first 5 minutes to 360 minutes, from 9:00-15:00 WITA. This is in line with Sarmad et al., who found that solar radiation intensity varies from 9:00-15:00 and increases from morning until reaching its maximum value at 13:00 [44]. The use of a dryer powered by rice husk energy resulted in an average drying temperature ( $T_d$ ) of  $69.06^{\circ}\text{C}$  with a range of  $51.29\text{--}81.90^{\circ}\text{C}$ . This temperature range resulted from using rice husk in the furnace for only one filling and without adding any additional rice husk mass. Furthermore, the lower initial temperature resulted from the rice husk undergoing a prior evaporation process. The moisture content of rice husk is 6-10%, and there is a drying zone in the biomass, namely the process of evaporating the water content before further heating occurs [45-47]. When rice husks are converted into charcoal, high temperatures are generated. Test results also show that the outlet temperature of the drying chamber ( $T_o$ ) remains quite high, averaging  $55.29^{\circ}\text{C}$  and ranging from  $46.2$  to  $64.11^{\circ}\text{C}$ . The drying temperatures inside and outside the drying chamber were 113.02% and 70.54% higher, respectively, compared to ambient temperature. At these temperatures, Figure 5 shows the decrease in the mass of the dried *Rengginang*.

Figure 5 shows a comparison of the decrease in *Rengginang* mass during the 360-minute test between the rice husk dryer and direct sun drying. The average mass of *Rengginang* in the rice husk energy dryer was 1086 g on each rack, while direct solar drying was 1086 g. The use of the rice husk energy dryer showed a faster decrease in *Rengginang* mass during 360 minutes compared to direct sun drying. This is influenced by the higher temperature used in the rice husk dryer. The rice husk dryer produced a final mass of 616.2 g, while direct sunlight drying produced 794 g. *Rengginang* initial moisture content is 48.27% wb. The moisture content %wb (wet basis) is the percentage of moisture content in a material calculated based on its wet weight.

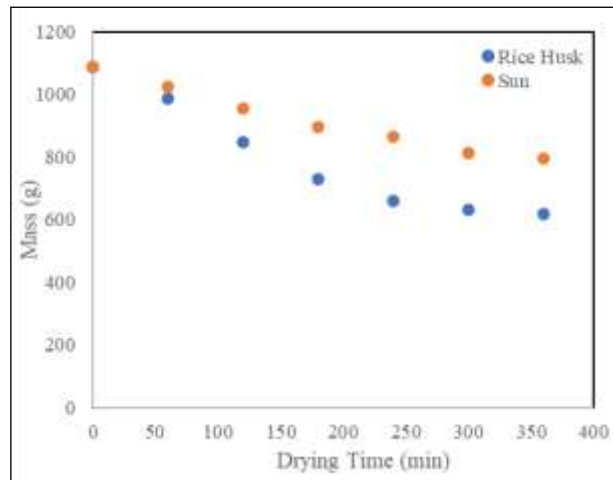


Figure 5: Comparison of drying *Rengginang* using rice husk dryer and direct sunlight. Source: Authors, (2026).

In this study, drying *Rengginang* for 360 minutes showed that drying using rice husk energy accelerated the reduction in the product's water content compared to conventional solar drying. Comparison data for drying using rice husk energy and direct sun drying are presented in Table 1.

Table 1: Comparison of data on rice husk energy dryer and direct sun drying.

Parameter	Rice husk energy dryer	Direct sun drying
Mass of initial materials (g)	1086	1086
Initial moisture content of material (%)	48.27	48.27
Final material mass (g)	616.2	794
Final moisture content (wb) (%)	8.83	29.25
Drying time (minutes)	360	360

Source: Authors, (2026).

Based on Table 1, the rice husk energy dryer significantly reduced the initial moisture content of *Rengginang* by 48.27% to 8.83% in 360 minutes. This value is within the ideal moisture content limit for *Rengginang* products ready for frying (<12%). The water content of *Rengginang* according to SNI 01-4307-1996 regarding rice crackers is a maximum of 12% [48]. This demonstrates that the rice husk energy dryer is operating optimally, with stable and efficient heat distribution and airflow. Meanwhile, sun direct drying yielded a final moisture content of 29.25% within the same drying time. This indicates that the drying process is not optimal due to differences in heating temperature and uneven air circulation. Table 1 shows how drying performance is highly dependent on technical conditions such as temperature, airflow, and heat distribution. Rice husk energy dryers provide stable heat and can be used at any time (independent of the weather), thus offering advantages in terms of time and quality. In addition, rice husks' abundant availability can reduce waste through their use in drying energy. Vast expanses of rice fields have the potential to utilize rice husk waste as a biomass raw material to support renewable energy [49]. Meanwhile, sun direct drying often requires more than a full day to reduce the moisture content to less than 12% due to its high dependence on weather, humidity, and direct sunlight.

Ergonomics studies have shown that these differences in performance have direct implications for workers' physical workload and duration of heat exposure. More energy-efficient rice husk drying means shorter labour time to achieve the final result, thus reducing exposure to high temperatures and lowering the risk of muscle fatigue and heat stress. This is particularly relevant in traditional food processing activities such as *Rengginang*, which are generally carried out manually in high-temperature environments. Conversely, sun direct drying shows suboptimal drying, which extends the work duration and increases static loads due to the need to regulate and monitor the dryer for longer periods. Furthermore, this inefficiency can impact the frequency of stirring and tray rearrangement activities, as well as increase muscle fatigue in the arms, back, and lower legs due to unnatural working postures. Therefore, an ergonomics thermal engineering approach in designing traditional rice husk energy dryers is not only technically superior but can also provide significant ergonomics benefits, such as reducing prolonged heat exposure, shortening work cycles, reducing the risk of musculoskeletal disorders, and increasing work comfort. This application, which is centered on humans as workers, is in line with research results that state humans remain important for adaptability and innovation, so human-machine integration is a crucial factor [50].

The importance of an ergonomics approach in evaluating the performance of drying equipment so that technological innovation prioritizes process efficiency and the long-term safety and health of workers.

## V. CONCLUSIONS

Drying *Rengginang* using rice husk energy for 360 minutes can increase the ambient temperature and optimally reduce the moisture content. The initial moisture content of 48.27% can be reduced to 8.83% when using rice husk energy, while under direct sunlight conditions, the reduction only reaches 29.25%. This indicates that factors such as drying temperature, air circulation, and rice husks influence the drying duration. From an ergonomics perspective, drying time impacts not only product quality but also workers' physical workload. Fast and effective drying can reduce heat exposure, repetitive manual activities, and the risk of musculoskeletal disorders. Conversely, suboptimal drying can potentially extend work time and increase physical fatigue. Utilizing rice husk energy as a heat source not only offers promising efficiency and sustainability but also contributes to increased work comfort if supported by ergonomic tools and process design. The practical implications of these results encourage the need to integrate technical and ergonomics approaches in the development of small and medium-scale food drying systems.

## VI. AUTHOR'S CONTRIBUTION

**Conceptualization:** I Gede Bawa Susana and Ida Bagus Alit.

**Methodology:** I Gede Bawa Susana.

**Investigation:** I Gede Bawa Susana and Ida Bagus Alit.

**Discussion of results:** I Gede Bawa Susana and Ida Bagus Alit.

**Writing – Original Draft:** I Gede Bawa Susana.

**Writing – Review and Editing:** I Gede Bawa Susana and Ida Bagus Alit.

**Resources:** I Gede Bawa Susana and Ida Bagus Alit.

**Supervision:** I Gede Bawa Susana and Ida Bagus Alit.

**Approval of the final text:** I Gede Bawa Susana and Ida Bagus Alit.

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