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DESIGN OF DRYER FOR SMALL FARMERS BASED ON THE STUDY OF ERGONOMICS THERMAL ENGINEERING APPLICATION

I Gede Bawa Susana[1], I Ketut Perdana Putra[2]
[1] Department of Mechanical Engineering, Faculty of Engineering, University of Mataram, Jl. Majapahit No. 62 Mataram-Nusa Tenggara Barat 83125 Indonesia
[2] Department of Electrical Engineering, Faculty of Engineering, University of Mataram, Jl. Majapahit No. 62 Mataram-Nusa Tenggara Barat 83125 IndonesiaMataram
Email: gedebawa@unram.ac.id

Abstract

The process of drying food ingredients by small farmers still relies on sunlight, with drying in open areas. This process produces less than optimal drying thermal temperatures, resulting in long drying times, and dried food ingredients are susceptible to dust and animal feces exposure. In addition, exposure to the sun's heat on workers causes additional workloads that impact fatigue. On the other hand, existing dryers are generally less affordable and do not pay attention to ergonomic aspects for small farmers with limited resources. Therefore, a dryer design solution is needed that is not only thermally efficient but also ergonomic and meets the needs and abilities of small farmers. Ergonomic thermal engineering combines the principles of thermal engineering and ergonomics to design systems and products that optimize energy and resources, improve worker thermal comfort, and reduce thermal stress and fatigue. This study was conducted by utilizing solar collectors through dryer design based on the anthropometric data of workers as users. The dryer was designed through an ergonomic thermal engineering study. The research aimed to design an efficient, energy-efficient, ergonomic, and affordable dryer for small farmers. It applied the principles of thermal engineering for drying efficiency and ergonomics for comfort and ease of use. Based on anthropometric data and percentile calculations, dimensions were obtained for the dryer design, such as the bottom shelf with a height from the floor of 66.88 cm based on the knuckle, the top shelf height of 123.8 cm from the floor based on standing eye height, and the height of the drying room air chimney from the floor is 177.59 cm based on the height of the upper reach. To avoid new problems with the dryer application, a table was designed as a work aid with a height of 84.31 cm based on the height of the standing elbow. Applying the principles of ergonomics thermal engineering can create systems and products that are more comfortable, safe, and efficient for workers.

Key words: Design, dryer, anthropometry, ergonomics thermal engineering

INTRODUCTION

The post-harvest drying process carried out by farmers predominantly involves drying under the sun. This process is carried out because it is cheap and easy. On the other hand, drying under the sun still has weaknesses, such as being very dependent on the weather and the temperature being less than optimal due to only relying on the thermal environment. In addition, workers who dry by drying will be exposed to the sun's heat. Exposure to heat in outdoor sun drying, such as in agriculture, causes risk factors for heat-related diseases such as cramps, fatigue, and muscle pain, as well as additional workloads for workers during the drying process (OSHA-1, 2024; Santosa and Bawa Susana, 2021).

Sun drying is generally carried out in open areas in the yard, roadside, and sometimes on the house's roof. Low temperatures in sun drying have an impact on long drying times and low-quality products. The average environmental temperature in drying food is 32.26^{o}C with a range of 29.38-33.88^{o}C (Alit and Bawa Susana, 2023). As a result of drying in the open, the product is exposed to dust, dirt, and animal disturbances as shown in Figure 1, which impact the final quality of the dried product.

Figure 1. Animal Disturbances in Drying by Drying in Open Areas Under Sunlight

Environmental conditions such as animals, insects, dust, dirt, and rain that re-wet the dried product are some of the causal factors that affect product quality (Ramirez et al., 2020; EI-Sebaii and Shalaby, 2012; Dhanushkodi et al., 2016). In addition, when drying products or food ingredients, workers experience additional workload in the form of exposure to hot sun and unnatural working postures. Workers' heart rate will increase due to continuous heat exposure.

Unnatural work postures increase the risk of muscle injuries, musculoskeletal disorders, and fatigue. Low productivity and increased health costs result from unnatural work postures that cause fatigue, muscle injury risk, and musculoskeletal disorders in workers. (Zheltoukhova et al., 2012; Bawa Susana, 2016). Unnatural and unusual working postures cause musculoskeletal complaints and increase the risk of work injuries due to exposure (Bridger, 2003; OSHA-2, 2024). Workers who carry out the drying process need the right tools that are easy to operate and comfortable. This requires a tool design that suits the needs of the user or worker. The active role or participation of workers as users is very much needed.

Workers' Participation as users is needed in the production process, in this case, the drying process, so that the work tools are appropriate and sustainable. A participatory approach is an effective way of procuring more profitable work tools, redesigning manual tasks, and facilitating physical workloads (Burgess-Limerick, 2018; Sormunen et al., 2022). With the participation of users of work tools, it can be found that workers need a shorter drying process with more comfortable work, such as a natural working posture and avoiding exposure to the sun's heat. Worker participation in the design of work tools is through anthropometric data. Work tools based on the worker's anthropometric data impact comfort in the production process. Anthropometry in human or worker interaction with work tools is used as an ergonomic consideration. Humans have different shapes and sizes, such as height, width, and weight, from one another (Wignjosoebroto, 2008). Anthropometric data is needed to match the tool and its user to create an effective, comfortable, safe, healthy, and efficient working atmosphere (Sari et al., 2020). Applying anthropometric data impacts a comfortable work posture for users or workers. A comfortable work posture is a body posture that is done naturally when working. A natural work posture can minimize Musculoskeletal injuries (Pratiwi et al., 2015). To meet the needs of workers in drying food materials such as coffee, corn, fish, etc., in terms of temperature, time, and comfort, ergonomics thermal engineering can be used as a solution. Ergonomics thermal engineering is a way or method of designing and optimizing thermal or temperature systems to improve human comfort, safety, and productivity in various work environments and daily life.

Small farmers need this for drying post-harvest products, which is still done traditionally. Inappropriate thermal conditions can have an impact on the dried food, as well as the health and productivity of workers. Thermal conditions are one of the most important and common occupational health problems in the workplace (Wardani et al., 2023). Preserving agricultural crops useful for several agricultural sectors is an important process through drying. Solar drying is a relatively cheap and effective method for drying agricultural products (Radhakrishnan et al., 2025). The benefits of ergonomics applications are creating effective, comfortable, safe, healthy, efficient and sustainable work through integration with mechanical (Bawa Susana et al., 2024). Ergonomics studies how to design equipment, systems, or work environments appropriate to human capabilities, limitations, and comfort. Ergonomic design is characterized by adapting to natural human postures and movements, reducing physical strain and risk of injury, increasing comfort and work efficiency, being easy to use, and considering factors such as body size, strength, reach, and user perception. In contrast, non-ergonomics does not consider aspects of human comfort and capabilities in design. Non-ergonomic equipment or work environments often cause fatigue, muscle pain, discomfort, and long-term injuries.

The research aimed to design a dryer that is efficient, energy efficient, ergonomic, and affordable for small farmers by applying thermal engineering principles for drying efficiency and ergonomics based on anthropometric data. The dryer design with ergonomics thermal engineering studies has a thermal goal so that drying takes place at an optimal temperature, saving time and costs. Ergonomically, the dryer is easy to operate, safe, and comfortable for the operator, increasing operator safety and reducing the risk of work accidents. The dryer design is a drying chamber and solar collector that applies anthropometric data of workers as users so that the work posture changes to be more natural and the temperature increases. The benefits of the dryer design with ergonomics thermal engineering studies are a guide or guideline in its application in the field.

METHODS

The study used ergonomics thermal engineering to design dryers for small farmers. The design results are expected to be used as a guide in field applications. The study was conducted through the mechanical field, which, in this case, was related to thermal principles and the ergonomics field, through workers' participation as users. Data was taken from workers who carried out the drying process by drying in direct sunlight. This data is in the form of anthropometric data or body dimensions needed to be used in the dimensions of the dryer design. Anthropometric data was taken from 6 workers who did traditional drying work in direct sunlight. The anthropometric data was then recalculated with percentiles. Based on the percentile calculation, it was then applied in the form of dimensions on the dryer. Percentile values indicate the number of parts per hundred people in a population with a certain body size, and percentile values are used in calculating anthropometric data (Wignjosoebroto, 2008; Iridiastadi and Yassierli, 2019). To increase the ambient temperature that has been used in drying food ingredients, a solar collector is designed. The solar collector functions to absorb sunlight. The ambient air is channelled into the solar collector so that the air that comes out of the solar collector becomes hot. The heat generated by the solar collector is collected and stored to be used as a heat source. The hot air is then channelled into the drying room. In addition, the non-ergonomic working posture of workers such as squatting, bending over, and far from reach which is often done when carrying out the drying process by drying can be prevented by applying a dryer design based on a thermal ergonomic study. Figure 2 shows the drying process carried out by fish craftsmen.

(a) (b)

Figure 2. Drying by Sun Drying is Done (a) In a Bent Working Posture, (b) On the Roof of the House

An ergonomics thermal engineering study was conducted to prevent unnatural working postures such as bending and out of reach, as presented in Figure 2, and avoid animal disturbances, as presented in Figure 1. The research used materials and tools, including 6 female workers, to obtain body dimensions or anthropometric data. Anthropometric data were measured based on the needs of the dryer design. Worker anthropometric data included hand grip height, standing eye height, upper reach height, and standing elbow height.

Knuckle height or gripping hand height is the vertical distance from the floor to the metacarpal (middle finger of the gripper). Subjects are measured in an upright standing position, arms straight down at the side of the body with fingers clenched and both feet standing straight, with weight centered on both feet. The measurement results are used to determine the height of the lower rack in the drying chamber. For all subjects to place the drying mat on the rack in the drying chamber, the lower rack height, the 5th percentile of the gripping hand height (knuckles), is used. Standing eye height is the vertical distance from the floor to the corner of the eye. Subjects were measured in an upright standing position with both feet balanced and weight concentrated on both feet. The measurement results determine the maximum height of the top shelf in the drying room. This is to make it easier for the subject to organize and see the results of drying the product. So that all subjects could reach and observe the drying results on the top shelf in the drying room, a 5th percentile standing eye height was used. The upper reach height is the vertical distance from the floor to the midpoint of the clenched fist. Subjects are measured in standing, upright positions, with arms straight up and hands clasped (can use a round, cylindrical object). The measurement results determine the maximum height of the air flue (air outlet) in the drying chamber. This makes it easier for subjects to maintain and close the air flue. For all subjects to reach and adjust the air flue in the drying chamber, the 5th percentile of the upper reach height is used. Standing elbow height is the vertical distance from the floor to the midpoint of the elbow. The subject is measured in a standing upright position, arms straight down at the side of the body, with both feet balanced and weight resting on both feet. The measurement results are used to determine the height of the work table when arranging and turning the anchovies before placing them in the drying room. So that all subjects could reach the drying surface, a 5th percentile table height of standing elbow height was used.

The results of anthropometric data measurements were then calculated using percentile values. For all subjects to reach the tool design, the 5th percentile value was used and calculated based on the measurement data's mean and standard deviation values .

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

$\bar{x}$ is the mean, and SD is the standard deviation, as shown in Equation 2.

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

x_i is measurement data, $\bar{x}$ is the average of the measured data, and n is the number of measured data.

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RESULTS AND DISCUSSION

Measurement of anthropometric data on female workers who do drying work by sun drying is used to design the dryer. This creates a natural working posture for workers as users of the tool. Anthropometric data on the hand grip height, namely the vertical distance from the floor to the metacarpal (middle finger of the hand grip). The subject is measured in an upright position, with arms straight down at the side of the body with fingers clenched into fists and both feet standing equally, with weight concentrated on both feet. The measurement results are used to determine the height of the bottom shelf in the drying room. So that all subjects could put the drying mats onto the rack in the drying room, the height of the bottom shelf in the drying room was used as a percentile of 5th hand height (knuckles). Anthropometric data of standing eye height is the vertical distance from the floor to the corner of the eye. Subjects are measured upright with both feet balanced and weight supported by both feet. The measurement results determine the maximum height of the top shelf in the drying room. This is to make it easier for subjects to arrange and see the results of drying the product. So that all subjects can reach and observe the drying results on the top shelf in the drying room, the height of the top shelf of the 5th percentile of standing eye height is used. Anthropometric data of upper reach height is the vertical distance from the floor to the midpoint of the fist. Subjects are measured in standing, upright positions, with hands straight up and clasped (can use round cylindrical objects). The measurement results determine the maximum height of the air chimney (air outlet) in the drying room. This makes it easier for subjects to maintain and close the air chimney. For all subjects to be able to reach and adjust the air chimney in the drying room, the 5th percentile of the upper reach height is used. The anthropometric data of the standing elbow height is the vertical distance from the floor to the midpoint of the elbow. Subjects are measured in an upright standing position, arms straight down beside the body, and both feet standing balanced, with weight supported by both feet. The measurement results are used to determine the height of the work table when arranging and turning the anchovies before being placed in the drying room. The 5th percentile of the standing elbow height table height is used for all subjects to reach the drying surface. The tool's design, based on the subjects' anthropometry, can improve work performance. Knuckel is a reference for the hand grip point in applications such as storage shelves, or factory tools to fit the worker's natural hand reach; Standing eye height as reference data for visual locations such as maximum allowable height; upper reach height for applications of the highest acceptable point limits related to hand operations; standing elbow height is reference data for determining the height of the work platform (Tarwaka, 2011; Pheasant and Haslegrave, 2018). The steps taken include determining important body dimensions in the design, determining the user population, calculating percentile values for each established body dimension, and applying them to the tool design (Tarwaka, 2011; Pheasant and Haslegrave, 2018; Wignjosoebroto, 2008).

Anthropometry is an ergonomics consideration in human or worker interaction with work tools. Humans have different shapes and sizes, such as height, width, and weight from one (Wignjosoebroto, 2008). To create a match between the tool and its user, anthropometric data is needed to create an effective, comfortable, safe, healthy and efficient working atmosphere (Sari et al., 2020). Anthropometric data of 6 female workers and its application in the form of percentiles as shown in Table 1.

Table 1. Anthropometric Data of Female Workers

Sample	Knuckle	Standing Eye Height	Height Reach Upper	Elbow Height Standing
1	67.4	124.2	178.4	88.5
2	67.9	124.4	180.5	89.2
3	68.2	125.1	182.5	91.4
4	69.1	125.5	185	92.1
5	70.1	126.2	186	101.3
6	70.2	126.4	187.5	101.4
Mean	68.82	125.3	183.32	93.98
Standard Deviation	1.17	0.908	3.473	5.86

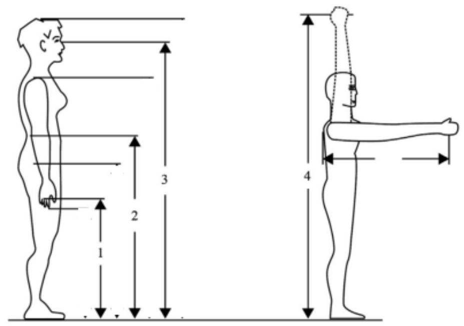


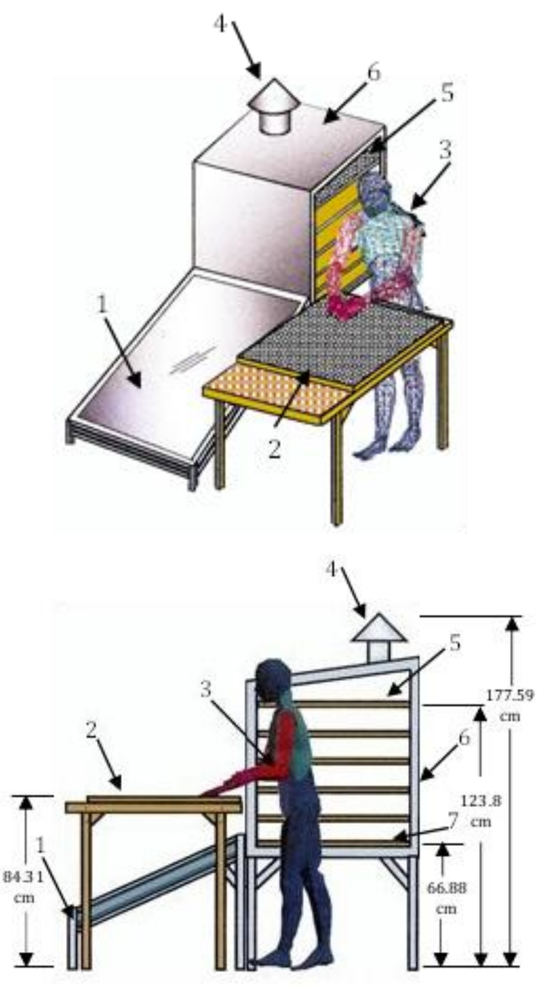
Figure 3. Schematic Diagram of Anthropometric Data of Female Workers, which Includes 1. Knuckle, 2. Elbow Height Standing, 3. Standing Eye Height, and 4. Height Reach Upper

The anthropometric data from Table 1 were then calculated using the 5th percentile values presented in Table 2.

Table 2. Average Percentile Score 5 (P5)

No	Data Types	Percentiles	Results (cm)	Details
1	Knuckle	P5	66.88	Lower Shelf of Drying Chamber
2	Standing Eye Height	P5	123.8	Upper Shelf Drying Chamber
3	Height Reach Upper	P5	177.59	Dryer Chamber Chimney
4	Standing Elbow Height	P5	84.31	Height of Work Table

Based on the data from Table 2, a dryer design can be made, as shown in Figure 4.



1. Solar Collector, 2. Work Assistance Desk, 3. Worker, 4. Air Chimney, 5. Top Shelf, 6. Drying Chamber, 7. Bottom Shelf

Figure 4. Dryer Design with Ergonomics Thermal Application

The dryer design, as shown in Figure 4, can produce hygienic products because the food is dried in a closed drying room. Compared to drying by sun drying, which is done in the open, the dried food is susceptible to exposure to dust, dirt, and animal disturbances. As shown in Figure 1, food that is dried by sun drying in the open is targeted by pets such as chickens, which have an impact on the emergence of damage to the product and is susceptible to contamination by dirt so that the product is not hygienic.

The dryer design, along with ergonomic thermal engineering studies, such as Figure 4, is an integration between the mechanical field, especially thermal and ergonomics. The worker's posture becomes more natural, from initially squatting to standing. In addition, workers are protected from exposure to sunlight because the drying process is carried out in the drying room, and workers do not need to supervise the dried food. Ergonomically, heat exposure and squatting work posture are additional workloads that workers should not accept. The work table, as shown in the design of Figure 4, aims to make it easier for workers to arrange or sort food before and after the drying process. This is a step so that new problems do not arise after using work tools due to ergonomic thermal intervention. Using ergonomic principles in a job related to humans as a centre is an effort to reduce the risk of occupational safety and health (Imada, 2000; Burgess-Limerick, 2018). Intervensi ergonomi secara luas berpengaruh terhadap penurunan keluhan muskuloskeletal *disorders* (MSDs) (Benos et al., 2020).

Thermally, the drying temperature can be increased due to the use of solar collectors. Solar collectors are the main devices in the thermal solar drying system that collect and absorb solar radiation, which is then converted into heat energy used for the drying process in the drying room by free convection. Applying solar collectors can increase the ambient temperature in conventional drying, with the drying air temperature reaching 60% (Al-Jethelah et al., 2021). In the study of Alit and Bawa Susana (2023), it was stated that solar collectors with wave plates made of zinc material could increase the environmental temperature by 34.54%. Solar dryers are a sustainable alternative by utilizing solar thermal energy to dry vegetables effectively. In addition, solar dryers can optimize vegetable preservation, promote energy efficiency in reducing post-harvest losses, and support environmentally friendly practices that align with global sustainability goals (Suraparaju et al., 2024). The use of solar energy for the drying process allows food to be more durable and can be stored longer without damage. One method of preserving food for a longer period that is convenient and easy to do is drying, which has been practised since the beginning of civilization as a post-harvest practice (Bahammou et al., 2022; Tagnamas et al., 2021; Vijayan et al., 2020). Solar energy applied in drying has several advantages; it can operate using solar energy (renewable) and can reduce drying costs by 27-80%, so that more profit is obtained (Şevik et al., 2019).

The right dryer for post-harvest food materials, especially on a small scale, is very much needed by rural communities. For the dryer to provide an optimal drying process that is easy to operate and comfortable for the operator, participation or input from the user is needed. This can be achieved by applying ergonomic thermal engineering studies when designing the dryer. The dryer is designed to optimize the drying thermal temperature and has an ergonomic design that makes it easy for the operator to operate. The design of the dryer with optimal thermal temperature can increase drying efficiency and product quality and reduce operational and maintenance costs. An ergonomic dryer design can improve operator safety. In addition, ergonomically, thermal comfort can be created for workers. Excessive heat conditions will cause fatigue and drowsiness, reducing work stability (Wardani et al., 2023), so thermal comfort is very much needed in work activities. Thermal comfort in drying is a comfortable and safe working environment for workers carrying out food-drying activities. Ergonomic thermal engineering combines the principles of thermal engineering and ergonomics to design systems and products that optimize energy and resources, increase worker thermal comfort, and reduce thermal stress and fatigue. Ergonomic thermal engineering focuses on the interaction between humans and the thermal environment at work or in everyday activities, with the aim of maintaining comfort, health and productivity, as well as ensuring safety (Bush, 2012; Parsons, 2012). Applying ergonomics thermal engineering principles can create systems and products that are more comfortable, safe, and efficient for humans.

CONCLUSIONS

The design of a dryer for small farmers based on a study of ergonomics thermal engineering applications can be concluded:

1. The drying room's design, based on the user's anthropometric data, provides dimensions such as the height of the lowest shelf from the floor, 66.88 cm, the height of the top shelf, 123.8 cm, and the position of the air chimney, 177.59 cm from the floor. This is to make it easier for workers to reach as users.
2. Utilization of solar collectors in the drying room to reduce exposure to solar heat on workers, as well as to optimize drying temperatures. Dryer design with ergonomic thermal engineering applications based on the user's body dimensions, so that work can be done comfortably.
3. The application of ergonomic thermal engineering combines the principles of thermal engineering and ergonomics, resulting in a dryer design with a solar collector integrated with the workbench to make it easier for workers to do their work in an effort to reduce thermal stress, musculoskeletal complaints, and fatigue.

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