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Addressing Ergonomics in Paddy Milling: Insights from RULA, Nordic Body Map, and Anthropometry

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ABSTRACT

A majority of the rice milling process in Indonesia has been categorized as small and medium enterprises that rely heavily on human labor during their operations. Such activities put human operators at high ergonomic risks, particularly in relation to the onset of musculoskeletal disorders (MSDs) due to postural stress, repetitive exertions, and sustained or static exertions. Ignorance of these ergonomic risk factors is likely to cause permanent disabilities in the future. As such, this study aims to identify ergonomics risk factors in the milling rice process using both the subjective method by Nordic Body Map Questionnaire and the observation method through Rapid Upper Limb Assessment (RULA). The results show that all milling rice operators reported symptoms in their shoulders and low back pain. The final score of RULA was seven or very high risk, indicating that investigation and changes are required immediately. A redesign of the existing step ladder was proposed, developed by an anthropometry-based design approach. The proposed design is expected could reduce the score to 4 or medium risk level.

Keywords: *RULA, Nordic Body Map, Musculoskeletal Disorders, Anthropometry, Rice Milling*

ABSTRAK

Sebagian besar proses penggilingan padi di Indonesia merupakan industri skala kecil dan menengah yang masih menggunakan tenaga manusia dalam kegiatannya. Aktivitas ini menempatkan manusia pada postur kerja beresiko secara ergonomi, khususnya terkait munculnya keluhan otot rangka (*musculoskeletal disorders / MSDS*) akibat tekanan posisi kerja, gerakan berulang, dan sikap menahan beban secara statis. Faktor risiko yang diabaikan berpotensi menimbulkan kecacatan jangka panjang. Penelitian ini bertujuan mengidentifikasi faktor resiko ergonomi postur kerja penggilingan padi menggunakan metode subjektif Nordic Body Map dan penilaian postur dengan metode *Rapid Upper Limb Assessment* (RULA) di UD Sumber Tani Agung, Gresik. Hasil penelitian menunjukkan keluhan terbesar dilaporkan pekerja di bagian bahu dan punggung bawah. Penilaian postur dengan metode RULA memberikan hasil sebesar 7 atau sangat beresiko sehingga perlu dilakukan penyelidikan dan tindakan segera. Untuk mengurangi faktor resiko ini dilakukan rancangan perbaikan terhadap pijakan tangga yang ada menggunakan perancangan berbasis antropometri. Dengan menggunakan data antropometri Indonesia dihasilkan usulan perbaikan pijakan tangga yang diharapkan dapat menurunkan faktor resiko menjadi 4 atau resiko sedang.

Kata kunci: RULA, Nordic Body Map, Keluhan Otot Rangka, Musculoskeletal Disorders, Antropometri, Penggilingan Padi

1. Introduction

In a nation where 95% of its population relies on rice as a staple food, the rice milling industry in Indonesia plays an important role in the national rice supply chain. Rice is the primary product of this industry and holds a strategic political commodity so the quality and quantity of domestically produced rice serve as indicators of national food security (Balitbang Pertanian, 2005). The critical role of this milling business can be observed from the large number of rice mills spread throughout rice-producing regions in Indonesia.

Currently, the rice milling industry employs over 10 million workers and processes more than 40 million tons of paddy rice into milled rice annually. However, a significant proportion still operates using simple technologies and relies heavily on manual labor (Rachmat, 2012). This is primarily because many of these mills are of small to medium scale.

While providing significant employment, especially to the local population, the reliance on manual labor in the rice milling process poses long-term health risks, particularly concerning musculoskeletal disorders (MSDs). Such disorders usually begin with complaints of excessive pain and can lead to anatomical changes in body tissues if persistently experienced (Stack et al., 2016). Within the agricultural sector, especially in paddy milling operations, some factors contributing to the emergence of MSDs include postural stress, repetitive exertions, and sustained/static exertions (Iridiastadi & Yassierli, 2017). If these risk factors are not controlled, they have the potential to cause permanent disabilities (Stack et al., 2016).

The World Health Organization (WHO) report reveals that the problem of MSDs is currently globally among the highest-ranked occupational diseases (Hämäläinen et al., 2017; WHO, 2021). This finding is further corroborated by national data (Ministry of Health of the Republic of Indonesia, 2019). This issue is also prevalent in the agricultural sector, with low back pain being a significant concern in both developed and developing countries (Benos et al., 2020). Thus, research concerning MSDs in the agricultural sector remains relevant, especially within small to medium-sized enterprises, where there is a limitation in resources, technical capacities, and often an oversight in occupational health and safety by business owners (Hermawati et al., 2014; Uswatun Khasanah et al., 2022).

Literature suggests that one way to mitigate these risks is through engineering approaches, specifically by isolating workers from hazards (Stack et al., 2016). This can be achieved by redesigning existing workplace facilities to reduce the strain or pressure on workers' postures. Furthermore, a well-thought-out redesign is expected to improve user acceptance of the tools, leading to better effectiveness and efficiency since workers would be familiar with these modified tools from previous experiences (Prayitnoadi et al., 2021)

Several studies in Indonesia have focused on identifying ergonomic risk factors in the posture of paddy farming activities. For instance, a study by (Susihono et al., 2019) redesigned paddy threshing technology, which effectively reduced postural stress values during the activities of feeding rice into the threshing machine and collecting grain. A more recent study by (Tirtasari et al., 2020) developed a paddy threshing aid that managed to reduce the RULA score from 6 (i.e., working in poor posture with a risk of injury from their work posture) to 4 (i.e., working in a posture that could present some risk of injury from their work posture). Moreover, (Arifin et al., 2022) compared the RULA and Rapid Entire Body Assessment (REBA) methods during the paddy milling process and found RULA scores of 7 and REBA scores of 9, both classified as high risk. However, this study did not offer solutions to mitigate these risks.

Despite existing research, there is still a need to identify work postures in paddy milling activities for several reasons. First, there is a limited number of studies addressing ergonomic risk factors in specific agricultural activities, although these tasks are commonly encountered in daily life within communities. Second, the demographics of the workers, geographical characteristics, and varying environmental conditions of agricultural activities also influence the extent of ergonomic risks (Neubert et al., 2017). Third, most proposed designs involve the procurement of machinery that requires considerable resources. Therefore, this study aims to identify risk factors in the paddy milling process of a small to medium-sized enterprise in Gresik using the Rapid Upper Limb Assessment (RULA) and Nordic Body Map (NBM) methods. Subsequently, it will design proposed workplace facility improvements using anthropometric methods.

2. Methods

This study is a cross-sectional descriptive analysis aimed at identifying ergonomic risk factors in the paddy milling process using the RULA and NBM methods. Additionally, an improvement of workplace facilities will be conducted using an anthropometric approach. The research methodology employed in this study is summarized in Figure 1.

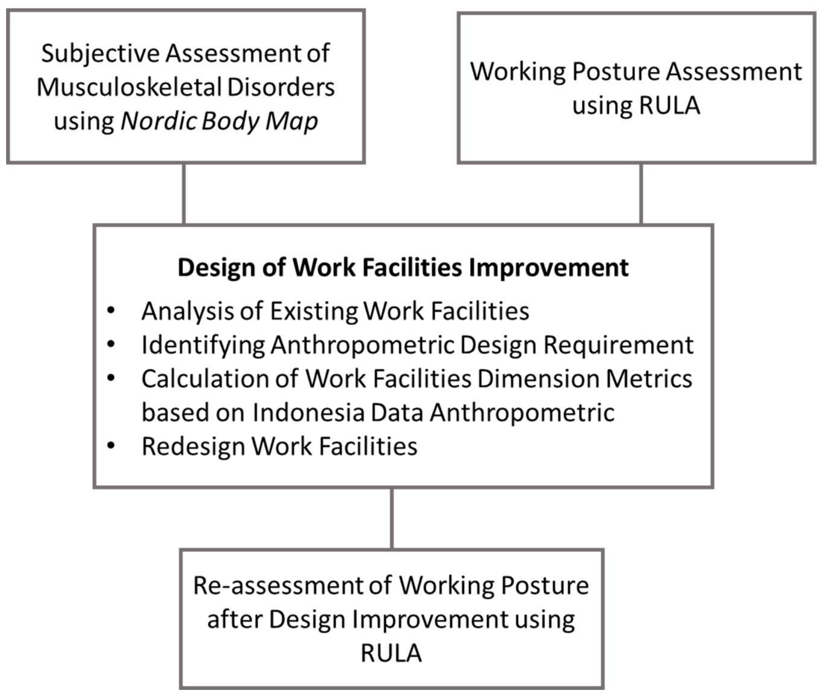

Figure 1. Research Method

2.1. Location, Population, and Sample

The study was conducted on the paddy milling process in the small to medium-sized enterprise "UD Sumber Tani Agung" located in the Ujungpangkah sub-district of Gresik. The population under study comprises all workers in that business unit, totaling 15 individuals. The sample for the study included all workers specifically involved in the paddy milling process, which amounted to three individuals. For observations using the RULA method, only one worker was randomly chosen as the observation sample, since the postures adopted by all three workers were roughly similar.

2.2. Existing Conditions

"UD Sumber Tani Agung" is a small to medium-sized enterprise (SME) in the agricultural sector that has specialized in paddy milling since 1991. This milling operation is classified as a small paddy mill (PPK) with a production capacity of approximately 10 tons per day or less than 2 tons of milled dry paddy per hour (Wahyuni, 2020). The business employs a total of 15 workers (14 males, 1 female) with an average work experience of 18.7 years (ranging from 2 to 30 years). The operational activities within the company include paddy drying (5 workers), paddy milling (3 workers), rice packaging (3 workers), rice storage (3 workers), and administration (1 worker). The rice processing operation is depicted in Figure 2.

In general, the paddy milling process consists of four stages: 1) lifting of paddy, 2) transferring paddy into a basin or bucket, 3) pouring the paddy into a hopper (machine input funnel), and 4) stirring the paddy within the hopper. This study specifically focuses on the posture during the paddy pouring into the hopper stage.

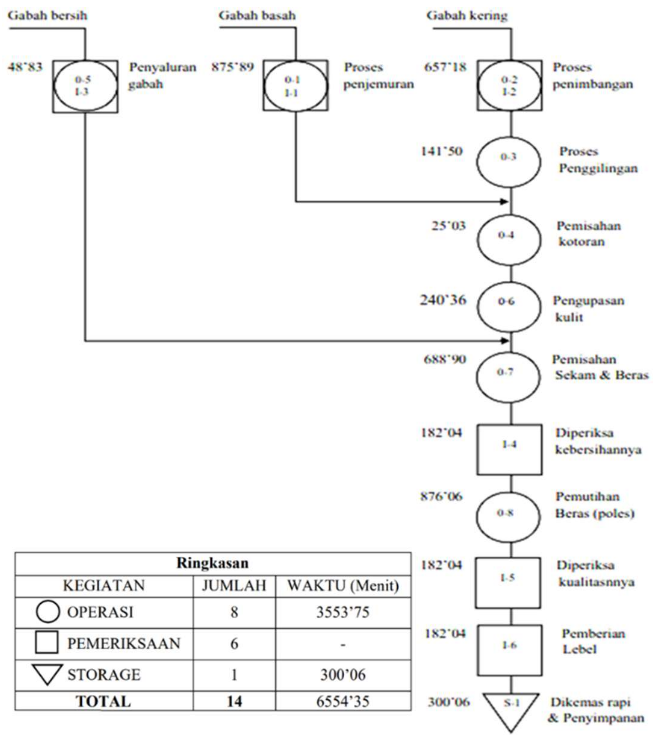

Figure 2. Operation Process Charts of Paddy Processing at UD Sumber Tani Agung

2.3. Nordic Body Map

The Nordic Body Map (NBM) questionnaire was employed to measure workers' perceptions of musculoskeletal complaints experienced due to work activities. The NBM questionnaire utilized has been adapted from the original version (Kuorinka et al., 1987). Respondents were asked to indicate whether they felt no pain, slight pain, moderate pain, pain, or severe pain in each body part over the past month. Figure 3 illustrates the body parts inquired about in the NBM questionnaire to aid respondents in identifying musculoskeletal complaints.

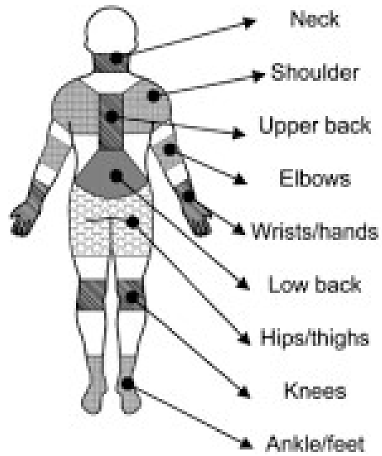

Figure 3. Body Parts Evaluated through the Nordic Body Map Questionnaire (Widanarko et al., 2016)

2.4. Rapid Upper Limb Assessment (RULA)

The Rapid Upper Limb Assessment (RULA) is a quick evaluation of ergonomic risk factors concerning the position or posture covering the upper body, namely the neck, back, wrists, and legs of the operator while working (Gómez-Galán et al., 2020). The RULA method has been widely used in various industries, including agriculture, and is the preferred method for assessing upper body MSD risk factors compared to REBA and Ovako Working Posture Analysis System (OWAS) (Kee, 2020; Mishra et al., 2018). In summary, the steps of the RULA method are:

1. Divide the observed posture results into two groups. Observers note the body posture angles during work and then categorize them according to the observed body parts into Group A and Group B.
2. The first group (A) consists of the upper arm, lower arm, wrist, and wrist twist. Group B comprises the neck, trunk, and legs. For repetitive activities, a score of +1 needs to be added to both Groups A and B. Additionally, a score for activities involving a load/force of 2-10 kg is added as +1 or +3 for weights >10 kg.
3. Determine the final score (C) from the combined score of A and B.
4. Determine the action level from the final score C. A final score of 1−2 means minimal risk, can be neglected, and no action is needed. A score of 3−4 is considered low risk, suggesting changes may be needed in the foreseeable future. A score of 5−6 indicates moderate risk and necessitates further action in the near term. A score of 7 or more is deemed high risk, and immediate changes are required.

The detailed RULA assessment worksheet can be seen in (Hedge, 2022).

2.5. Anthropometric-Based Design

The proposal for workplace facility design was conducted using an anthropometric approach based on the principles of workspace design for standing workstations that can accommodate the majority of users (Iridiastadi & Yassierli, 2017). The data used for the design originates from the Indonesian male anthropometry database, which can be freely accessed at https://antropometriindonesia.org/.

3. Results and Discussion

3.1 Subjective Assessment of Musculoskeletal Disorders Using Nordic Body Map

Table 1 summarizes the results from the Nordic Body Map questionnaire for all three operators. From these results, it is evident that all operators reported complaints in the shoulder and lower back regions. Additionally, two operators experienced issues in other body parts, specifically the wrist and knees. These subjective assessments will subsequently be confirmed through posture evaluation using the RULA method conducted by the researcher.

Table 1. Operator Characteristics and Summary of Musculoskeletal Complaint Measurements Using Nordic Body Map

Body Part	Operator 1	Operator 2	Operator 3
Neck	×	VP	×
Shoulder	MP	VP	VP
Upper Back	MP	×	×
Elbow	MP	×	×
Low Back	MP	VP	P
Hand/Wrist	×	VP	P
Buttock/Thigh	MP	×	×
Knee	×	P	MP
Ankle /Foot	×	×	P

Note. x = No Complaint / No Painful, MP = Moderately Painful, P = Painful, VP= Very Painful

3.2. Posture Assessment using RULA

The observed working posture and corresponding posture angles for Group A can be seen in Figure 4. The scores obtained for the upper arm, lower arm, wrist, and wrist twist are included in the body posture table for Group A (refer to Table 2).

Table 2. Working Posture Assessment Group A

Upper Arm	Lower Arm	1		2		3		4	
		Wrist 1	Twist 2	Wrist 1	Twist 2	Wrist 1	Twist 2	Wrist 1	Twist 2
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

The score value of 6 was further added by an activity score of 1 because the activity was repetitive, occurring more than 4 times per minute. An additional load score of 1 was added since the lifted weight was 10 kg, making the total score for Group A amount to 8.

The assessment results for Group B, along with the observed working posture angles, can be seen in Figure 5, while the score values can be found in Table 3. The Group B score of 3 was added with an activity score of 1 and a load score of 1, bringing the total score for Group B to 5.

Figure 4. Working Posture Assessment for Group A

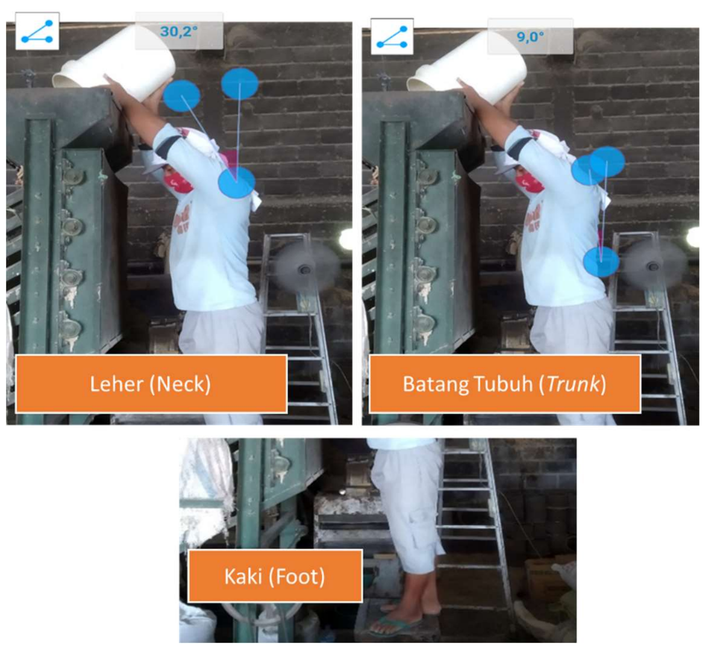

Figure 5. Working Posture Assessment for Group B

Table 3. Working Posture Assessment Group B

	Trunk Postur Score											
	1		**2**		**3**		**4**		**5**		**6**	
	Legs		**Legs**		**Legs**		**Legs**		**Legs**		**Legs**	
	1	2	1	2	1	2	1	2	1	2	1	2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

The next step is to determine the Group C score, which is the sum of Groups A and B, resulting in a final score of 7, placing it in the high-risk category. Based on the action level category, the rice milling activity in the production department with a standing posture falls into a very high-risk level, necessitating immediate further investigation and corrective action.

A total score of 7 was also found by (Arifin et al., 2022; Susihono et al., 2019) using the same method for rice milling tasks. When compared with the subjective measurement, the Nordic Body Map (NBM), posture assessment using the RULA method indicates much higher ergonomic risks. In general, observational method assessments are more accurate as they do not involve respondent perceptions, which can be biased (Schneider et al., 2019).

3.3. Re-Design Work Facilities

To reduce ergonomic risk factors, an improvement of a step ladder (or platform) design is proposed. The currently available step ladder facility is shown in Figure 5.

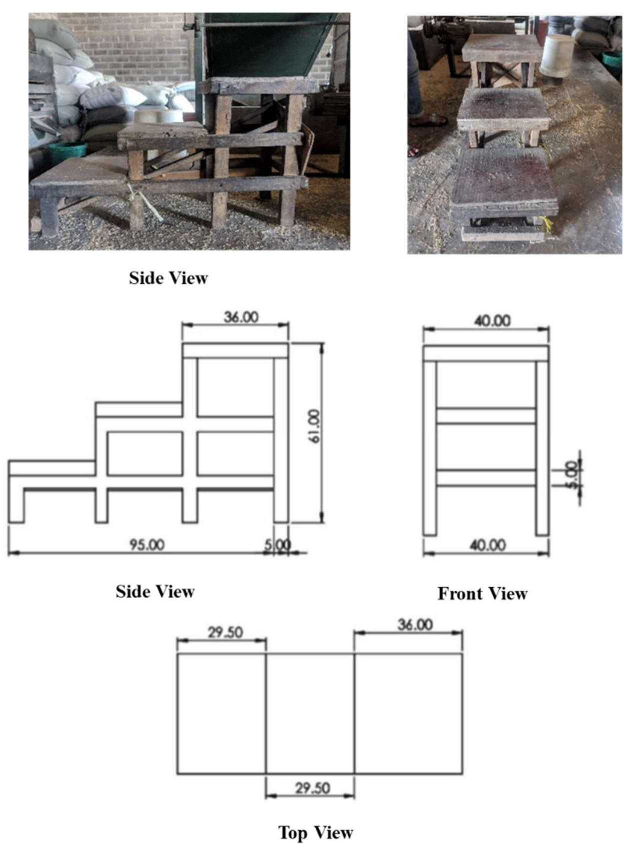

Figure 5. Dimension and Existing Step Platform: Side View, Front View, and Top View

The improvement design utilizes anthropometric-based design principles for standing workstations (Iridiastadi & Yassierli, 2017). The required body dimensions are as follows:

1. Standing shoulder height. This dimension is used to determine the maximum height of the step platform and to understand the distance between the shoulders and the machine's height.
2. Knee height. This data is essential to ascertain the maximum height for the appropriate leg distance and for stepping upward.
3. Upper arm length. This dimension serves as a measurement for the distance between the upper arm and the machine when the worker is holding a load in an elevated position.
4. Forearm length. This data is necessary to determine the distance between the forearm and the machine when carrying a load in an elevated position.
5. Forward hand reach. This reach data is used to establish the maximum hand reach of the operator to the hopper or inlet funnel.
6. Leg length. This dimension is vital for determining the maximum length of the step platform.
7. Foot width. This data is used to ascertain the maximum overall width of the step platform.

Table 4. Dimension and Percentile for the Proposed Design Step Ladder

N	Dimension	Percentile	Size (cm)	Standard Deviation	Total
1	Standing shoulder height	50	133.4	17.2	150.6
2	Knee height	50	51.3	6.9	58.2
3	Upper arm length	50	32.9	5.9	38.8
4	Forearm length	50	42.3	8.6	50.9
5	Forward hand reach	50	66.7	10.6	77.3
6	Leg length	50	23.7	3.4	27.1
7	Foot width	50	9.6	1.7	11.3

The required data dimensions were extracted from the Indonesian anthropometric database at the 50th percentile level, based on a design principle that could accommodate the average users. From the selected percentile, the standard deviation was added (see Table 4). By incorporating allowances, the final dimensions of the tool were generated, as indicated in Table 5. In addition to dimensional changes, improvements were made to the materials used. Hollow steel frames were considered suitable due to their durability yet ease of mobility. Furthermore, a solid wood overlay was added to the stair treads to provide comfort to the operator and reduce the risk of slipping when ascending the stairs.

Table 5. Material and Dimension of Proposed Step Ladder

Material		Dimension (cm)
Overall Ladder Steel Frame	Height	174 cm
	Length	110 m
	Width	50 cm
Hollow	Height	3 mm
	Width	3 mm
	Thick	2.6 mm
Flat Step Length	Length	30 cm
	Width	50 cm
Wooden Step Cover	Length	20 cm
	Width	58 cm
	Thick	3 cm
Bolts	Diameter	4.6 cm

	Length	4	cm

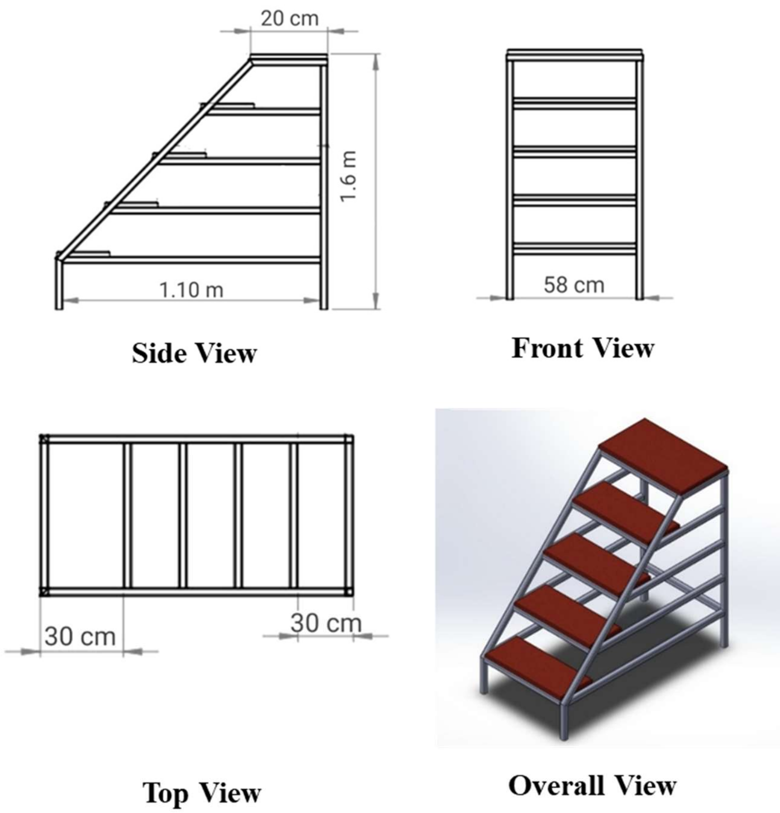

Figure 6. Proposed Ladder Step Design.

Based on various considerations, including the height of the machine, anthropometric data, and material selections, we calculate the dimensions for the proposed design of "Pijakan Tangga" (step ladder or platform) as follows:

1. Ladder Height. The height of the ladder is determined based on the machine's height of 2.32 meters.

$$\text{Ladder Height } (Lh) = mh - kh = (232 - 58.2)\ cm = 173.2\ cm = 1.74\ m$$

   Where:
   mh = machine height
   kh = Knee height

2. Ladder Length. The ladder will have four steps each measuring 20 cm in length and a fifth (topmost) step that is 30 cm long, making a total of five steps.

$$\text{Ladder Length } (Ll) = Fl \times 4 + 30\ cm = 20\ cm \times 4 + 30\ cm = 110\ cm = 1.10\ m$$

   Where:
   Fl = flat step length

3. Ladder Width. The width of the ladder is determined by considering four times the average foot width.

$$\text{Ladder Width } (Lw) = (11.3\ \times 4)\ cm = 45.2\ cm \approx 46\ cm$$

An additional margin is added for safety and comfort, rounding off the total width to 50 cm.

4. Hollow Steel Dimensions. The ladder's framework will be constructed from black hollow steel bars in a rectangular shape. These bars will measure 3 x 3 mm in width and have a thickness of 2.6 mm.
5. Flat Step Length. The length of the flat part of each step is based on the average foot length data from Table 4. After adding a buffer, each step will be 30 cm in length.
6. Wooden Step Cover. The steps will be covered with solid wood planks for comfort and reduced slip risk. Each plank will measure 58 cm in width, 20 cm in length, and have a thickness of 3 cm.
7. Bolts. The bolts used to attach the wooden planks to the steel steps will have a diameter of 4.6 cm and a length of 4 cm.

The procedure for using the ladder in the rice milling process is as follows:
1. The operator picks up a bucket filled with unhusked rice
2. The operator climbs the ladder from bottom to top.
3. The operator carries the bucket filled with unhusked rice weighing 25 kg. After that, the bucket is lifted, and the rice is poured into the milling machine through the hopper or inlet chute, positioning the shoulders, arms, and hands straight forward.

The improvement assessment of posture using the RULA method for the simulation of ladder usage can be seen in Figure 7. Table 6 shows a summary of the RULA score calculations. The final score decreased from 7 to 4, or from very high risk to relatively low, with further changes needed in the future. By introducing necessary adjustments for user comfort and safety, the new ladder design aims to provide an ergonomic solution for workers. The final materials and dimensions of the redesigned ladder are presented in Table 5, while Figure 6 shows a visual representation of the design.

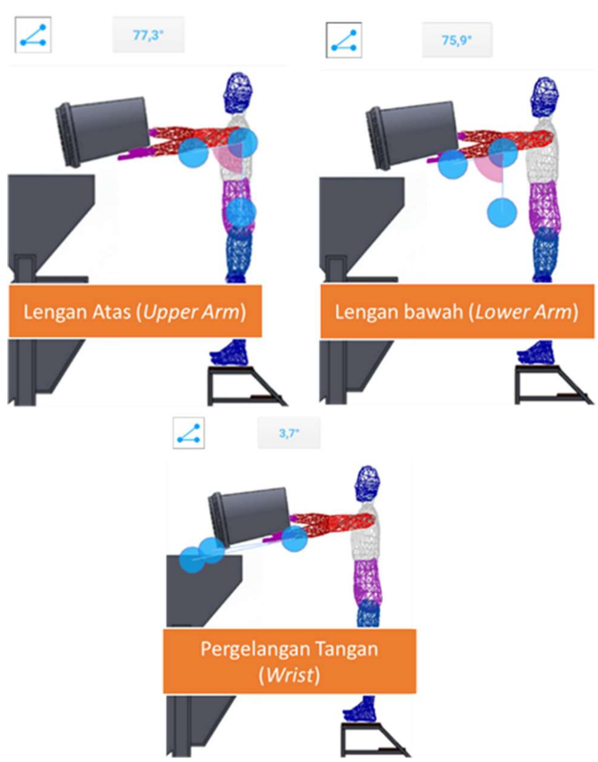

Figure 7. Simulation Assessment of Group A Posture After Implementing the Proposed Improvements.

Table 6. Posture Assessment of Group A for the Proposed Improvements.

Upper Arm	Lower Arm	1		2		3		4	
		Wrist	Twist	Wrist	Twist	Wrist	Twist	Wrist	Twist
		1	2	1	2	1	2	1	2
1	1	1	2	2	2	2	3	3	3
	2	2	2	2	2	3	3	3	3
	3	2	3	3	3	3	3	4	4
2	1	2	3	3	3	3	4	4	4
	2	3	3	3	3	3	4	4	4
	3	3	4	4	4	4	4	5	5
3	1	3	3	4	4	4	4	5	5
	2	3	4	4	4	4	4	5	5
	3	4	4	4	4	4	5	5	5
4	1	4	4	4	4	4	5	5	5
	2	4	4	4	4	4	5	5	5
	3	4	4	4	5	5	5	6	6
5	1	5	5	5	5	5	6	6	7
	2	5	6	6	6	6	7	7	7
	3	6	6	6	7	7	7	7	8
6	1	7	7	7	7	7	8	8	9
	2	8	8	8	8	8	9	9	9
	3	9	9	9	9	9	9	9	9

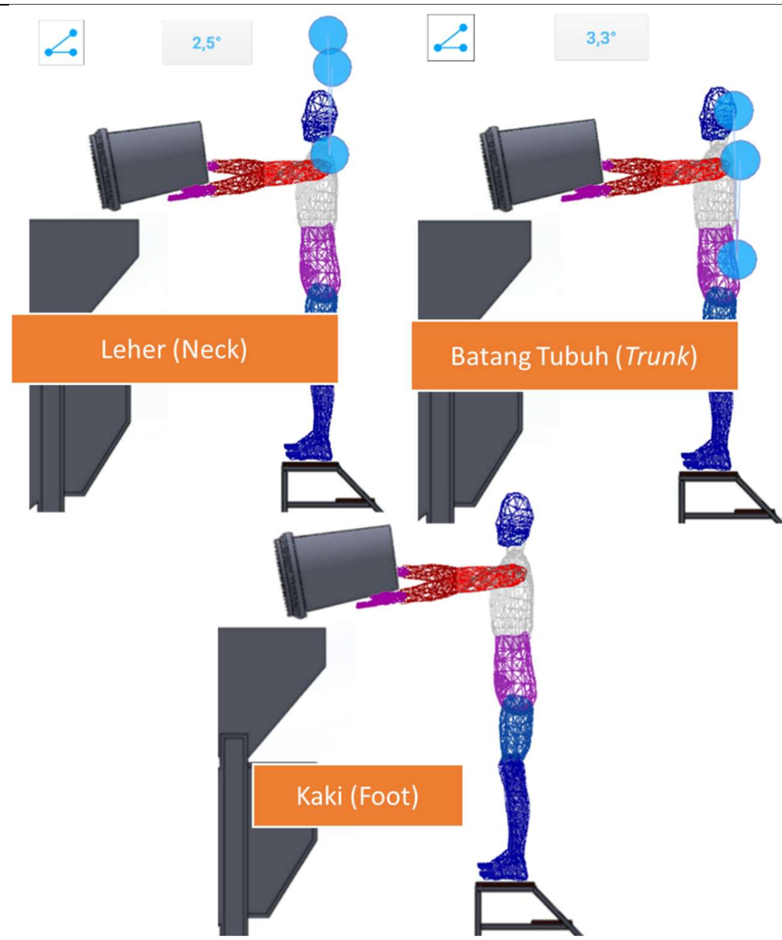

Figure 8. Simulation Assessment of Group B Posture After Implementing the Proposed Improvements.

Table 7. Posture Assessment of Group B for the Proposed Improvements

	Trunk Postur Score											
	1		**2**		**3**		**4**		**5**		**6**	
	Legs		**Legs**		**Legs**		**Legs**		**Legs**		**Legs**	
	1	2	1	2	1	2	1	2	1	2	1	2
1	1	3	2	3	3	4	5	5	6	6	7	7
2	2	3	2	3	4	5	5	5	6	7	7	7
3	3	3	3	4	4	5	5	6	6	7	7	7
4	5	5	5	6	6	7	7	7	7	7	8	8
5	7	7	7	7	7	8	8	8	8	8	8	8
6	8	8	8	8	8	8	8	9	9	9	9	9

4. Conclusion

Our findings indicate that rice mill operators subjectively experience the most significant muscular discomfort in the shoulder and lower back areas. An evaluation using the RULA posture assessment method yielded a final score of 7, indicating a high risk and necessitating immediate interventions. To mitigate the injury risk associated with working postures, improvements were made to the ladder facility based on anthropometric principles. This redesign decreased the risk score to 4, which is comparatively low.

A limitation of this study is that the proposed improvements have not been practically tested in the workplace, meaning that the actual reduction in risk is based solely on simulations. Future research can implement these suggestions and determine whether there's not only a decrease in risk factors but also an increase in workplace productivity. Another limitation is that the study only examined one posture, that of pouring unhusked rice. Further research is necessary to examine other postures in rice milling and other operational processes.

Declaration of Conflict of Interest

The authors declare that there are no potential conflicts of interest related to the research, writing, and/or publication of this article.

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