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Ergonomic Analysis of Small-Scale Palm Sugar Starch Processing Industry in Rancakalong Village, Sumedang Regency

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Abstract

Rancakalong village, Sumedang Regency, has been known for its small-scale palm sugar starch processing industry since 2013. This industry produces starch from palm trees, which is crucial for food and beverages. Generally, the processes involved in processing palm sugar starch include (i) splitting of the palm, (ii) grating, (iii) coarse fiber screening, (iv) fine fiber screening, (v) harvesting, and (vi) drying. Initial evaluations indicated that the workers experienced physical discomfort during their work. Therefore, this study aimed to analyze the ergonomic aspects of processing palm sugar starch, including the working posture, standard time, workload, noise, and vibration. Based on the analysis, the risk level for each work element in processing palm sugar starch fell into the high-risk (score 8-10) and very high-risk (score 11-15) categories. These risks cause discomfort due to inappropriate work posture and duration, necessitating significant changes. The standard time required for each work element was as follows: 212.88±28.43 seconds/kg (palm splitting), 363.45±12.90 seconds/kg (grating), 95.08±9.74 seconds/kg (coarse fiber screening), 192.05±21.27 seconds/kg (fine fiber screening), 35.57±5.78 seconds/kg (harvesting), and 1821.01±41.09 seconds/kg (drying). Regarding workload analysis, processing palm sugar starch activities fell into the moderate category with total energy cost (TEC) values ranging from 92.66±1.50 265.55±3.88 kcal/hour. Regarding noise and vibration analysis, the grating work element was identified as the station with the highest exposure, i.e., 96.00±0.82 dB and 1.6±0.05 m/s^2, respectively. The results of this study could be used as a basis for developing more efficient work procedures, maintaining health, and improving safety in the processing of palm sugar starch.

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1. Introduction

Palm Arenga pinnata (*Arenga pinnata* Merr.) is a palm plant in most parts of Indonesia in tropical climates. To achieve optimal growth and production, Aren palm plants should be planted above 1,200 m above sea level, with an average temperature of approximately 25°C (Fatah and Sutejo, 2015). Based on statistics for 2020 - 2022, the largest area of smallholder palm plantations is the West Java Province, which is 15,020 ha. One of the regencies in West Java that has a role in the development of palm plantations is the Sumedang Regency, which has a total area of 1,275 Ha and a productivity of 2,246 kg/Ha (Jamil et al., 2021).

The Aren palm plant offers the advantage of being fully utilisable, making it a valuable product with numerous economic benefits. The utilization carried out by the community includes palm fruit processed into 'kolang-kaling', palm sap processed into sugar, leaf bones, and coir processed into broomsticks, and palm stems processed into palm starch flour (Azhar et al., 2021). This plant has many advantages and potential for development in the food industry, especially in the production of palm starch flour. Its starch content, which ranges from 26-37%, can be utilized in food processing, such as cendol, cakes, bread, meatballs, vermicelli, and noodles, which use Aren palm starch flour as the basic ingredient (Setyabudi, 2013).

Rancakalong Village, Sumedang Regency, has a small industry producing palm starch that has been quite popular since 2013. According to Thoriq et al., (2022), knowledge regarding processing palm starch flour using technology is generally passed down from one generation to another. However, in practice, the processing of palm starch flour in Rancakalong Village is still performed manually, and the technology used is relatively simple. Aren palm starch flour is obtained by extracting starch from the piths of unproductive palm stems to produce sap (Nugroho et al., 2019).

The processing of Aren palm trunks carried out in the palm starch flour processing small industry in Rancakalong Village begins with splitting the palm using an axe. Subsequently, the palm stems were grated using a simple diesel-powered grating machine to separate the pith from the palm stems. The pith obtained from the grating process is then removed from the palm starch by stirring and filtering in a tub with running water. Water-containing starch was precipitated to separate the starch and water. Precipitated palm starch was harvested using a rake. After harvesting, palm starch was packed into plastic sacks and hung to reduce the water content. The wet starch was then spread on tarpaulin and dried using the sun's heat for one day to obtain dry palm starch flour ready to be packed into sacks.

Currently, manual handling of palm starch is inevitable. Especially in palm starch processing activities, workers use much human power, such as routinely carrying heavy loads. Other problems include noise and vibration from machinery, lack of standardized time to complete work, unergonomic work postures, and workloads, which can reduce comfort, health, and work efficiency (Negara et al.,). Manual work, such as splitting with an axe, exposes workers to several physical conditions, such as exertion, forced postures, and repetitive movements that can result in injury, wasted energy, and inefficient working time. Field observations show several problems related to the ergonomic aspects of processing palm starch flour. There are four physical stress factors during the processing of palm starch flour: time, load, posture, and working conditions.

A worker needs references and recommendations for their work. Ergonomic studies on palm starch flour processing are required to improve comfort, health, and work efficiency. The ergonomic approach to work design aims to achieve harmony between humans and work systems. Human movements in doing their work are ergonomically designed to minimize the risk of limb pain, fatigue, and pain (Syuaib 2016). Activities that can improve work efficiency include testing the noise and vibration generated by the machine, which is then compared with work safety standards, determining a production time reference, conducting posture evaluations, and evaluating operator workload. The approach used to assess the activities was biomechanical analysis, time, and workload studies (Sutalaksana et al., 2006). Therefore, this study aimed to analyze the ergonomic aspects of palm starch flour processing. The results of this study can be used to develop work procedures to improve the efficiency, health, and safety of palm starch flour processing activities.

2. Materials and Methods

2.1 Location of Area Starch Processing Industry

This research was conducted in a small industry that processes palm starch flour (‘Aci Kawung Pak Endang’) in Sukamaju Village, Rancakalong District, Sumedang Regency, West Java. A palm starch processing plant was established in 2013. Initially, there were two small palm starch processing industries in Sukamaju Village. Over time, the number of palm starch processing industries in Sukamaju village has increased to eight small industries. These industries operate from 7.30 a.m. until 5 p.m. and from Monday to Sunday. Based on the results of surveys and interviews, workers can grate as many as 35 palm trunks with lengths ranging from 50 - 60 cm per day. The production capacity of this palm starch processing plant per day produces 300 – 400 kg of wet palm starch packed into sacks. The mill sells wet starch at Rp 4,000/kg and dry starch at Rp 7,000/kg (Thoriq et al., 2022). The markets for palm starch produced by this factory are Bandung and Sumedang.

The palm starch processing in the 'Aci Kawung Pak Endang' palm starch processing industry was performed mechanically and manually. The mechanical method involves machines, whereas the manual method relies on human labor. Both mechanical and manual processing require workers. Labor is one of the aspects necessary for palm starch processing. Humans as laborers are different from machines; therefore, they have several problems, such as labor availability, different abilities of personal, work habits, and different skills.

2.2 Work Elements in Palm Starch Flour Processing

In this study, there were six working elements in the processing of palm starch flour: (a) splitting, (b) grating, (c) coarse fiber screening, (d) fine fiber screening, (e) harvesting, and (f) drying. The locations of each of these work elements are shown in Figure 1.

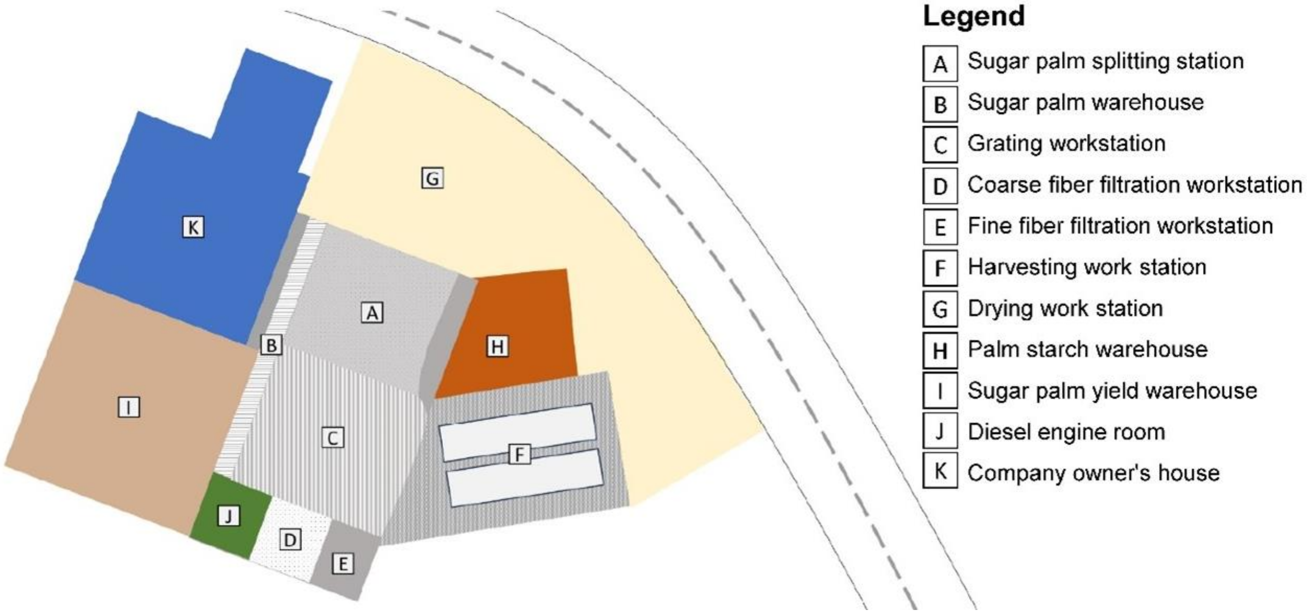

Figure 1. Location plan for the palm starch flour processing industry.

Each work element is explained as follows. (1) Splitting: This work element starts by taking the palm from the actual storage pile, followed by splitting the actual using an axe weighing less than 5 kg. The Aren palm is split into four parts to facilitate the grating process. (2) Grating: This process starts with collecting split Aren logs and then grating them to separate the pith from the periphery. (3) Coarse fiber screening: This work element starts by mixing the grated pith into a tub with running water, followed by screening activities where the coarse fibers are separated. (4) Fine fiber screening: This work element starts with stirring the results of the first screening so that the starch does not settle, and then the fine fiber in the form of slurry is separated and returned to be put back into the previous tub screening. (5) Harvesting palm starch: This work element starts from draining the water contained in the tub so that it leaves starch attached to the bottom of the tub, which is then collected using a rake and put into a sack that has been hung. (6) Drying: This work element starts with spreading the palm starch on the tarp until the process of leveling the palm starch so that it is spread out and can dry evenly. All of these work elements will be evaluated in terms of ergonomic aspects to provide comfort and improve efficiency at work.

2.3 Ergonomic Analysis

This study used a survey method for the palm starch processing industry. Sample determination was performed using the purposive sampling method because the sample population was small and the activity of making palm starch flour was homogeneous. The sample of this study included 4 subjects aged 27 – 45 years who worked on their work shift (Table 1). These subjects were selected based on their work experience, which showed that the four subjects were workers with more than five years of experience in the palm starch processing industry. The survey data were then descriptively analyzed, and the ergonomic aspects evaluated in this palm starch flour processing industry included: (a) work posture analysis, (b) time analysis, (c) workload analysis, and (d) noise and vibration analysis on machine.

Table 1. Physical characteristics of subjects involved in ergonomics evaluation.

Subject	Gender	Age (year)	Height (cm)	Body Weight (kg)
1	Male	41	172	59
2	Male	27	163	52
3	Male	27	166	62
4	Male	45	173	54

2.3.1 Work Posture Analysis

The Rapid Entire Body Assessment (REBA) method was used to analyze the work posture during palm starch flour processing. The risk level categories and corrective actions based on the REBA scores are shown in Table 2. Arms, wrists, and legs were analyzed. Workers recorded each activity for each work element during the processing of palm starch flour. Each work element in the processing of palm starch was simulated as a mannequin to facilitate the calculation of angles in REBA analysis. The REBA analysis results in the value of one worker for each work element based on daily tasks. This is because of the placement of each worker in a particular work element in the palm starch flour processing process that corresponds to their tasks. In each image collected, critical aspects such as the worker's neck, back, arms, wrists, and feet are analyzed. The evaluation of posture and work movements is then processed using Ergofellow Software to contribute to understanding and improving ergonomics in the workplace.

Table 2. Risk level categories and corrective actions based on REBA scores.

Action level	REBA score	Risk level	Corrective action
0	1	Negligible risk	Not necessary
1	2 – 3	Low	May be necessary
2	4 – 7	Medium	Necessary
3	8 – 10	High	Necessary and soon
4	11 – 15	Very high	Necessary urgent

2.3.2 Time Analysis

A time study is an attempt to determine the length of working time required by a trained worker to complete a specific job at a normal work rate and in the best possible working environment

(Wignjosoebroto 2003). Time measurement is an attempt to obtain an objective criterion. Determining the time for a job affects the determination of production systems, such as the wage system, scheduling work and machines, factory layout arrangements, and budgeting.

This study used the stopwatch time study method to observe the working time in the small palm starch flour processing industry. The number of observed cycles (N) was 30 for the work elements of splitting, grating, coarse fiber screening, fine fiber screening, palm starch harvesting, and drying, with a confidence level of 95% and an accuracy level of 5%. Data processing begins by analyzing the time data for each work element obtained using a stopwatch.

This analysis produces the cycle time (Equation 1), normal time (Equation 2), and standard time (Equation 3), which can be used to evaluate each work element. where, W_s is the cycle time, W_n is the normal time (s/kg), W_b is the standard time (s/kg), x_i is the i-measurement data, p is the adjustment factor based on the Westinghouse value, and is the allowance factor (%).

$$W_s = \frac{\sum x_i}{N} \tag{1}$$

$$W_n = W_s \times p \tag{2}$$

$$W_b = W_n + (W_n \times a) \tag{3}$$

The calculation of this leeway factor refers to Sutalaksana et al., (2006). It is calculated based on factors such as energy expenditure, work attitude, work movement, eye fatigue, workplace temperature, atmospheric conditions, and good environmental conditions. Based on the evaluation, the allowance factor for each work element had a range of values between 26% and 47% (Table 3).

Table 3. Allowance factors for various work elements.

Factor	Allowance factors for various work elements (%)					
	Pb	Pr	Pk	Ph	Pn	Pg
Energy expended	19	4	7.5	7.5	12	30
Work posture	4	1	7	7	4	7
Work movements	0	5	3	3	0	0
Eye fatigue	0	0	0	0	0	0
Working temperature conditions	5	5	5	5	5	5
Atmospheric conditions	0	0	0	0	3	0
Environmental conditions	5	10	10	10	3	3
Total	33	26	32.5	32.5	32	47

Description: Splitting (Pb), grating (Pr), coarse fiber screening (Pk), fine fiber screening (Ph), harvesting (Pn), and drying (Pg).

2.3.3 Workload Analysis

Workload is the burden placed on a person when doing a job. The pulse rate increases as a function of workload and oxygen consumption. An increase in pulse rate indicates a physical or mental workload, as there is a linear correlation with physical energy consumption (physical energy cost). Continuous data samples of pulse rate during an activity are useful indicators of psychophysiological workload. The greater the exertion required to perform an activity, the faster the heart and pulse beats. (McCormick and Saunders 1987). In this study, workload analysis was calculated based on the Interface Ratio of Heart Rate (IRHR) and Total Energy Cost (TEC) parameters for each work element in processing palm starch flour. IRHR is the relative ratio between a person's pulse rate when performing an activity and resting. High and low IRHR values reflect an activity's qualitative workload (vigor), whereas TEC is the total energy consumption rate of a person performing an activity. The TEC value for processing activities was calculated by summing the calorie requirement required by the body to metabolize with the calorie requirement needed to perform the activity.

The IRHR and TEC values can be calculated using Equations 4 and 5, respectively. where, HR_{work} is the pulse rate when working (bpm), HR_{rest} is the pulse rate at rest (bpm), *WEC* as work energy cost (kcal/min), and *BME* is basal metabolic energy (kcal/ min).

$$IRHR = \frac{HR_{work}}{HR_{rest}} \quad (4)$$

$$TEC = WEC + BME \quad (5)$$

$$BME = \frac{VO\,(\frac{\text{ml}}{\text{min}}) \times 5\ \text{kcal}}{1000\ \text{ml}} \quad (6$$

The BME values for each person differed according to body dimensions and gender. The BME value is equivalent to the value *VO* (volume of oxygen consumption) influenced by the body dimensions, where 1 litre of O_2 is equivalent to 5 kcal (Equation 6). The occupational level categories based on the IRHR and TEC values are shown in Table 4.

Table 4. Fatigue level categories based on IRHR and TEC values.

Category	IRHR[a] value	TEC[b] (kcal/h) value
Low	$1.00 < IRHR < 1.25$	100-200
Medium	$1.25 < IRHR < 1.50$	>200-350
Heavy	$1.50 < IRHR < 1.75$	>350-500
Very heavy	$1.75 < IRHR < 2.00$	None

Source: [a]Syuaib (2016), [b]Minister of Manpower of the Republic of Indonesia (1999).

2.3.4 Noise and Vibration Analysis on Machine

Noise is an unwanted sound in an environment with a certain level and time that can disrupt the health and atmosphere. In contrast, machine vibration is caused by mechanical devices, part of which reaches the body of employees and can affect work. Mechanical vibration generally disturbs the body because it causes irregular movements, both of which are irregular in intensity and frequency. This study measured the noise and vibration values of machines in the palm starch flour processing industry using sound level and vibration meters, respectively.

Vibration and noise measurements were performed at each station location on the work element while the machine was operating. The measuring devices were placed at points that matched the operator's position while working. The noise measurement procedure followed the SNI 7231:2009 standard, where the measurement points were adjusted to the operator's position and the measuring instrument was set parallel to the operator's ear, namely, on the right and left ears of the operator. In addition, noise measurements were performed on shredding machines with and without palm materials. This measurement used a sound level meter placed close to the shredding machine as the noise source. Vibration measurements were taken on the operator's seat and legs while the machine was operating. This vibration value is the average of three axes, namely x, y, and z. The measurement parameters for noise and vibration are expressed in units of the noise value (dB) and vibration value (m/s^2). The noise and vibration measurements were repeated three times to ensure accurate results.

2.4. Data Analysis

Each parameter measured in the ergonomic analysis of palm starch flour processing was repeated at least three times. Data were statistically analyzed based on the mean and standard deviation using Microsoft Excel. Furthermore, the ergonomic analysis measurement results were compared with the safety standards set by the industry worker safety regulations.

3. Result and Discussion

3.1 Work Posture Analysis

The operator's body movements during palm starch flour processing greatly affect safety and comfort. Figure 2 shows the postures of the work elements at various stages of the palm starch flour processing process, including (a) splitting, (b) grating, (c) coarse fiber screening, (d) fine fiber screening, (e) harvesting, and (f) drying. In general, the REBA analysis results show that the risk level in each work element in the processing of palm starch flour is high (score 8 – 10) and very high (score 11 – 15). Thus, each work element requires immediate and current corrective actions (Table 5). Splitting and drying are high-risk work processes. In splitting, the worker's back posture is bent over 60^o and the foot posture rests on one foot. When swinging the axe upward, the worker's upper arm has an angle of 125^o and the forearm has an angle of 73°. Splitting work has similar characteristics to hoeing work; the characteristics of the work are working with swing motion, which is similar to splitting (Irwanto dan Rubiono, 2019). The work postures carried out are very high-risk and cause complaints of muscle pain because repetitive movements and dominant use of static postures on the legs increase the risk of work postures such as complaints in joints, ligaments, and tendons (Setyawan et al., 2022).

Figure 2. Posture of work elements at various stages of the palm starch processing process, including: (a) splitting, (b) grating, (c) coarse fiber screening , (d) fine fiber screening , (e) harvesting, and (f) drying.

Table 5. Risk level categories and corrective actions based on REBA scores.

The work element	REBA score	Analysis results	
		Risk level	Corrective action
Splitting	11	Very high	Necessary urgent
Grating	9	High	Necessary and soon
Coarse fiber screening	9	High	Necessary and soon
Fine fiber screening	12	High	Necessary and soon
Harvesting	9	High	Necessary and soon
Drying	13	Very high	Necessary urgent

In the drying work element, the worker's neck posture was bent downward by 35° to observe the distribution of palm starch to be dried. The back is bent at an angle greater than 61°, and workers bear weight in a squatting position and use their feet as a fulcrum. The supported load was more than 10 kg (Sutalaksana et al., 2006). The upper arm was raised upwards at an angle of more than 116° to spread palm starch. Workers hold this posture for more than a minute and there are several small repetitive movements per minute. Heavy support on the legs causes the worker to hold this posture unstably. According to Wisudawati and Djana (2018), the physical burden will be heavier if working with unnatural postures, such as in a squatting position, because the nervous system and soft tissues are traumatized so that the stability of the body is disrupted because of the slouching posture. Workers who work in squatting postures tend to experience the risk of musculoskeletal disorders in the knees, calves, and thighs, where the legs play a role as weight support, resulting in discomfort in the legs, such as sharp pain.

Furthermore, the work elements of grating, coarse fiber screening, fine fiber screening, and harvesting are high-risk. For example, workers sit in the grating work element while holding on to the handle grip to maintain balance when pushing the palm fiber. The worker's upper arm has an angle of 60° and the forearm has an angle of <42.5°. The leg was bent at an angle of 35°. The worker's right leg was the most dominant leg in this work, so there were complaints on the right side of the body. The worker sat while pressing the sugar palm towards the grater, so there was pressure on the sitting posture (Malik et al., 2021). The sitting posture of leaning back at an angle of 41.5° causes the neck to bend forward by 22° which adjusts to control the grating process. For example, Malik et al. (2021), a tense or rigid sitting posture can cause up to 140% pressure. A tense sitting posture requires more back muscle or nerve activity than a forward-leaning sitting posture. To overcome this, on the grating machine chair for the work element of processing palm starch flour, there is a backrest that is padded so that complaints of lower back pain in workers can be minimized (Munyaneza and Sohn 2022).

3.2 Time Study Analysis

3.2.1 Normal Time

Under normal conditions, normal time is when workers complete their work reasonably without excessive effort (Wignjosoebroto 2003). Normal time is determined by calculating the cycle time with the amount of data based on the manual time study to fulfill the data sufficiency test. The normal time for each work element in palm starch flour processing is shown in Figure 3. Based on the analysis, the normal time for the splitting work element is 160.06±28.43 seconds/kg, grating is 75.46±9.74 seconds/kg, coarse fiber screening is 274.30±12.90 seconds/kg, fine fiber screening is 144.94±21.27 seconds/kg, palm starch harvesting is 27.57±5.78 seconds/kg, and 1238.79±41.09 seconds/kg on the drying work element. The value obtained shows the normal time required to complete one cycle on one work element, which has been considered based on the work environment conditions and the workers' ability to complete their work (Sukania and Teddy 2014). The normal time was the highest in the drying work element. This is related to the fact that palm starch flour has a relatively high water content. Water must be removed completely or mostly from raw materials to produce high-quality palm starch flour. The drying process should ensure the desired moisture level is achieved without damaging the flour structure or properties.

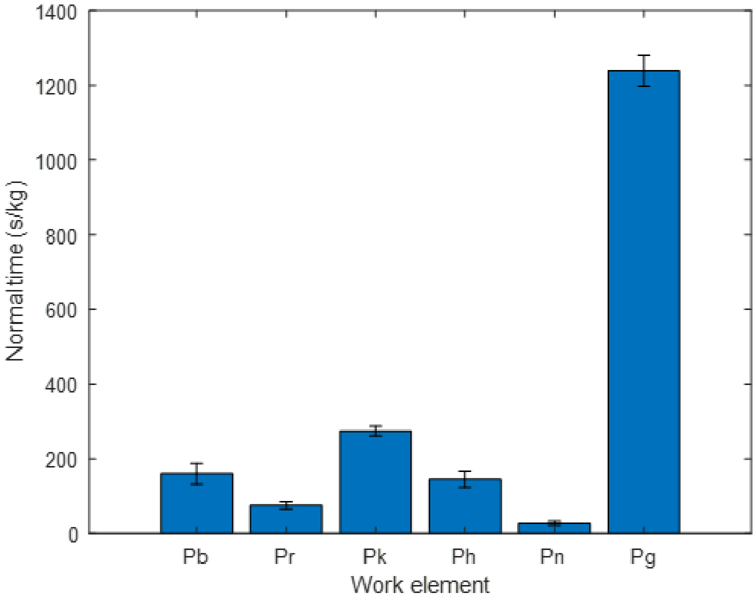

Figure 3. The normal time for each work element in the processing of palm starch flour, namely: splitting (Pb), grating (Pr), coarse fiber screening (Pk), fine fiber screening (Ph), harvesting (Pn), and drying (Pg).

The normal time value of manual labor is influenced by the rhythm of muscle movement and the work method. Muscular rhythm refers to the physical speed of the worker in completing the work. The method of doing a job refers to a sequence of specific steps repetitively performed by workers. According to Wignjosoebroto (2003), the factors affecting normal time are skill, effort, working conditions, and consistency. In addition, the adjustment factor also played an important role in performing work (Table 6). Based on the analysis results, the value of the adjustment factor for each work element falls into the p>1 category. This is a very good category because workers are experienced in their fields. This aligns with the workers' conditions, where their work experience has been more than five years.

Table 6. Adjustment factor values for various work elements.

The work element	Westinghouse value				Total	Performance rating
	Skills	Effort	Conditions	Consistency		
Splitting	0.11^{B1}	0.02^{C2}	-0.07^{F}	0.00^{D}	0.06	1.06
Grating	0.11^{B1}	0.05^{C1}	-0.07^{F}	0.01^{C}	0.1	1.1
Coarse fiber screening	0.11^{B1}	0.05^{C1}	-0.07^{F}	0.01^{C}	0.1	1.1
Fine fiber screening	0.08^{B2}	0.02^{C2}	-0.07^{F}	0.01^{C}	0.04	1.04
Harvesting	0.11^{B1}	0.05^{C1}	-0.07^{F}	0.01^{C}	0.1	1.1
Drying	0.11^{B1}	0.05^{C1}	-0.07^{F}	0.00^{D}	0.09	1.09

Explanation: Superscript symbols, consisting of letters and/or numbers, correspond to the categories of Westinghouse rating levels (excellent, good, poor, and average).

3.2.2. Standard Time

The standard time is obtained by multiplying the normal time by the value of the allowance factor. The standard times for each work element in processing palm starch flour are listed in Table 7. The work element of palm starch flour processing activity, which takes the longest time, is the drying work element, which is 1821.01±41.09 seconds/kg. The work element that requires the least time is the harvesting work element for 35.57±5.78 seconds/kg.

Table 7. Standard time for each work element in palm starch flour processing.

Work element	Allowance factors value	Standard time (s/kg)
Splitting	0.33	212.88±28.43
Grating	0.26	95.08±9.74
Coarse fiber screening	0.33	363.45±12.90
Fine fiber screening	0.33	192.05±21.27
Harvesting	0.29	35.57±5.78
Drying	0.47	1821.01±41.09

The allowance factor values for the processing activities of palm starch flour are diverse. This is because each activity was carried out with a different work attitude. In the grating activity, a value of 1% is obtained because of the work attitude when the grating is sitting and included in the light work. However, work that requires bending repetition movements, such as coarse fiber screening, fine fiber screening, and drying activities, has a higher value of 7%. The leeway factors considered in this study included labor expended, work attitude, work movement, eye fatigue, workplace temperature, atmospheric conditions, and good environmental conditions.

Eye fatigue factors, working temperature conditions, atmospheric conditions, and good environmental conditions are part of the work environment conditions considered in the allowance factor. Tyas and Sunuharyo (2018) state that a good working environment can increase job completion time. The eye fatigue factor is influenced by the light level at a workstation, and a good light level is one of the factors that provides good vision conditions so that the operator will find it easy to see the workpiece. (Guntur and Putro, 2017). A fatigue factor value of 0% indicates the low eye fatigue that occurs in workers, which is characterized by the absence of eye irritation, headaches, and workers' sensitivity to the environment. In the palm starch processing industry, there is no need for a view with a high concentration and accuracy.

3.3 Workload Analysis

The clarity level was obtained from the calculation of IRHR and TEC, which are presented in Table 8. The IRHR value reflects a person's capacity to do a job using the ratio between work and rest. The fatigue level based on IRHR for palm starch flour processing ranged from 1.17±0.01 to 1.53±0.01. The IRHR value was included in the low-to-heavy category. The IRHR value is influenced by the rate of increase in the pulse rate; the higher the activity intensity, the more the pulse frequency will increase. This is the body's natural response to meet increased blood supply needs. Based on the analysis, the IRHR value in each work element had a small quantitative difference. This shows that workers' fatigue level in all work elements was relatively the same.

Table 8. Evaluation results of fatigue levels in palm starch flour processing based on IRHR and TEC calculations.

Work element	IRHR (a.u.)	TEC (kcal/h)	Category
Splitting	1.53±0.01	265.55±3.88	Heavy
Grating	1.40±0.01	256.13±5.50	Medium
Coarse fiber screening	1.44±0.02	130.82±2.95	Medium
Fine fiber screening	1.17±0.01	92.66±1.50	Low
Harvesting	1.50±0.03	231.47±16.74	Medium
Drying	1.29±0.04	214.56±14.42	Medium

Workload based on quantitative values is calculated based on the energy consumption rate required by the body for metabolism and performing an activity. The total energy expended on each work element while performing its activities is obtained from the energy consumption rate of each worker in units of time.

According to Table 8, the fine-fiber screening work element has a low workload. The total workload required for the fine fiber screening process was 92.66±1.50 kcal/hour. This means that workers do not have excessive work-activity intensity. Unlike the splitting work element, this work falls into the heavy workload category. This is due to the greater intensity of activity, that is, workers require great energy during work. The higher the intensity of the activity, the higher the workload, and the higher the workload, the higher the exposure to risk at work.

Overall, the workload category in palm starch flour processing activities was medium. This is supported by work environment factors such as a comfortable temperature for workers (23-25°C), below the threshold value of heat exposure that should not be exceeded during 8 h of work. The skill level of workers with 5 years of work experience also affects the workload experienced by each worker. Workers who have been trained have the advantage of better physical condition than workers who have not been trained. This is due to the body's adaptation that occurs in workers trained to process palm starch flour. Thus, trained workers experience increased strength, endurance, flexibility, and muscle coordination relevant to their activity. According to Tyas and Sunuharyo (2018), changes occur when workers are trained to complete an activity, namely increased muscle strength and endurance, to support movement agility and reaction speed when working.

3.4 Noise and Vibration Analysis

The results of the noise and vibration analyses on various work elements of palm starch processing are shown in Figure 4. Based on Minister of Health Regulation Number 70 of 2016 concerning Industrial Work Environment Health Standards and Requirements, workers with a work duration of 8 hours/day have a Threshold Limit Value (TLV) of 85 dB. Based on the analysis, only one work element meets the safe TLV for noise, i.e., drying (81.67±0.47). Work elements such as splitting (87.67±0.94 dB), grating (96.00±0.82 dB), coarse fiber screening (93.33±0.47 dB), fine fiber screening (92.33±0.94 dB), and harvesting (85.33±0.47 dB) have NAB exceeding safe limits (>85 dB). The work element with the highest noise exposure value is the grating. This is because the grating work element has a grating machine that is a noise source in the work environment. In addition, the location of the splitting, coarse, and fine fiber screening work elements adjacent to the grating work element causes the noise to spread to the other work elements.

The noise measurements of the grating machine with and without palm material are listed in Table 9. The noise of the grating machine increased significantly when the palm juice was processed (104.8±3.72 dB) compared to the condition without palm juice (87.2±0.48 dB). A high noise value occurs when the palm is pressed and rubs against a rotating blade. When used, the noise generated by the machine causes a loud sound because of the friction between the tool's blade and material. Noise is an unwanted sound and is one of the causes of occupational health problems in the work environment. Based on the interview results, the operator complained that there was a difference; the operator's hearing in the left ear was lower than that in the right ear. The operator's hearing level temporarily decreased after the operation of the grating machine. Nasution (2019) stated that an exposure of 96.6 dB per day can cause hearing loss due to the accumulation of repeated exposure to high noise.

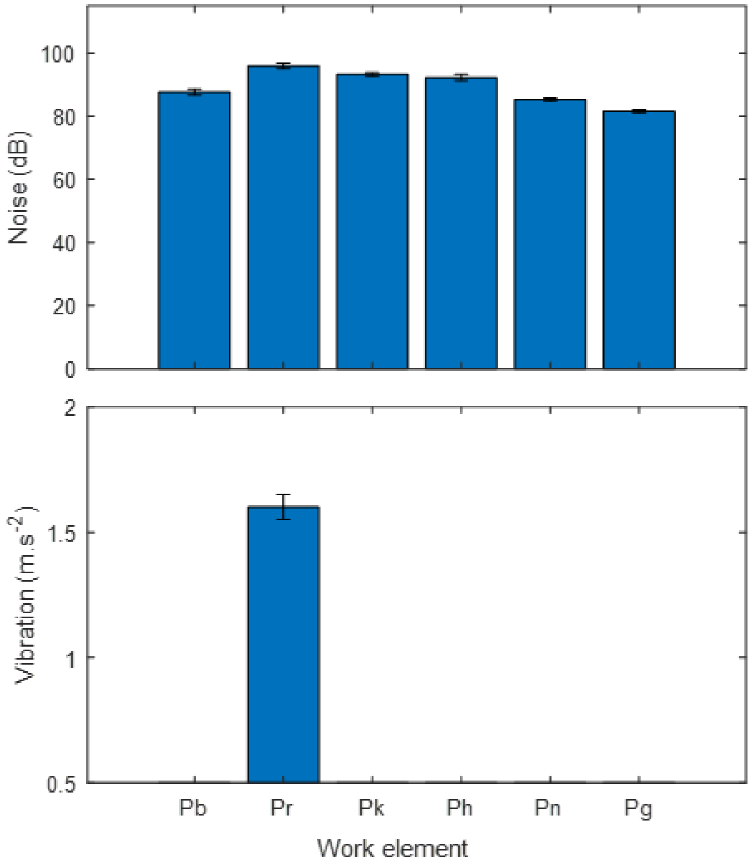

Figure 4. Noise and vibration analysis results for various work elements of palm starch flour processing, namely, splitting (Pb), grating (Pr), coarse fiber screening (Pk), fine fiber screening (Ph), harvesting (Pn), and drying (Pg).

Table 9. Measurement of grating machine noise with and without processed sugar palm material.

Condition of the grating machine	Noise value (dB)
Without materials	87.2±0.48
With materials	104.8±3.72

Recommendations to address high noise exposure can be provided in three aspects: operator, machine, and location. Operators recommend using ear protective equipment in the form of earmuffs that can reduce noise exposure by ≥ 85 dB. Earmuff usually comes with a value Noise Reduction

Rating (NRR), which is a measure of its effectiveness in reducing noise. The higher the NRR value, the greater the device's ability to reduce sound. Correct and compliant use, in accordance with Minister of Health Regulation Number 70 of 2016, can reduce exposure to high noise. Furthermore, the recommendation for diesel engines used in palm grating is to use a protective 'casing 'as a sound damper. Using a polyurethane 'casing, ' which can absorb sound energy owing to its porous nature, reduces noise in diesel engines. Thoriq and Sutejo (2017) modified the design of a sago grating machine by adding a grated cylinder cover as a step to reduce noise and increase work safety and security factors. The last recommendation is related to the location. The proper placement of machinery can significantly reduce noise levels. For example, the grating machine should be placed separately from other work elements in palm starch processing to reduce the noise generated.

Regarding vibration, of the six work elements, the grating is the only workstation with a vibration exposure value (1.6±0.05 m/s^2). The grating work element has a grating machine that is a noise source in the work environment. Whole-body vibration from mechanical vibration of the grating machine through the seat and footrest. Vibrations in the machine have mechanical properties transmitted to the body, particularly from the seat and leg support (Rahmawati and Suwarni 2018). Mechanical vibrations expose Most machine mechanical forces to the worker's body. In contrast to airborne vibrations whose effect is acoustic, mechanical vibrations result in resonance of the organs of the body, so that the effect is mechanical whose effect can damage body tissue cells and disrupt the metabolism of the human body (Wibowo et al., 2011).

Ministry of Manpower and Transmigration Number 13 of 2011 states that the threshold value for vibration in direct or indirect contact with the whole body is set at 0.5 m/s^2. Based on the vibration exposure of the operator's seat, workers are exposed to vibrations that fall under the uncomfortable category. This is because the foam used cannot dampen vibrations from the machine, causing fatigue, and the workers are exposed to the risk of lower back pain (Munyaneza and Sohn 2022).

The vibration of the operator's feet originates from the vibration generated by the contact of the palm with the grater that is pushed using the feet. The vibration produced at the operator's feet exceeds the threshold for a worker to be exposed to such vibration and is included in high-frequency vibration (Munyaneza and Sohn, 2022). This is because the operator's feet are closer to the vibration source and are in direct contact with the machine. To reduce vibration exposure, operators use rubber shoes. However, more effort is needed to reduce vibration exposure to reduce the risk. Controls that can be taken to reduce the risk from whole-body vibration include considering the selection of seating, including its suspension, taking breaks to allow tired muscles to recover, limiting the duration of exposure, and maintaining the machine, especially the parts that are in direct contact with the operator's limbs. Reducing vibration exposure can be done as in the design of the sago grating machine frame carried out by Thoriq and Sutejo (2017), who used a gasoline motor and focused on the main seat of the engine that can withstand the vibration of the engine during use. In the frame of this machine, there is a hopper and grated cylinder cover that can reduce exposure to vibrations throughout the body, especially on the legs, so that fatigue is reduced.

Ergonomic evaluation of small-scale palm starch processing industries is a complex challenge. Future research could focus on the relationship between equipment specifications, worker work posture, and physiology. By collecting comprehensive data on the equipment specifications, it is possible to design equipment that is in line with ergonomic principles. Thus, it is possible to evaluate the impact on workers' posture during the use of such equipment and its effect on the risk of injury and fatigue.

4. Conclusion

Palm starch flour processing is used to obtain starch from palm plants as a raw food and beverage industry material. This study analyzed the ergonomic aspects of palm starch flour-processing activities. The REBA analysis results show that the risk level in each work element in the processing of palm starch flour is high (score 8 - 10) and very high (score 11 - 15). Thus, each work element requires immediate and corrective actions. These risks cause discomfort owing to work attitudes and work duration that are not in accordance with the standard; therefore, changes are urgently needed. The standard time required for each work element is as follows: 212.88±28.43 seconds/kg (splitting), 363.45±12.90 seconds/kg (grating), 95.08±9.74 seconds/kg (coarse fiber screening), 192.05±21.27 seconds/kg (fine fiber screening), 35.57±5.78 seconds/kg (harvesting), and 1821.01±41.09 seconds/kg (drying). In terms of workload analysis, palm starch flour processing activities were categorized as moderate with TEC values ranging from 92.66±1.50 to 265.55±3.88 kcal/hour. Regarding noise and vibration analysis, the work element with the highest noise and vibration exposure values is the grater, which is 96.00±0.82 dB and 1.6±0.05 m/s^2. This ergonomic analysis can be a work reference and applied to the small-scale palm starch flour processing industry so that workers can prioritize occupational health and safety.

5. References

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