Reducing MSDs and physical workload of manual- harvesting peasant

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Abstract. The peasant who owns small paddy field does their harvesting activity manually using sickle and wooden-bench manual thresher. Harvesting activity using those tools make peasant work in bad posture, and it is done repeatedly in a long period which increases the risk of Work-related Musculoskeletal Disorders (WMSDs) and physical workload. The aim of the study is to reduce WMSDs and physical workload of the peasant by redesigning the tools used in harvesting activity. The proposed way is evaluation using a digital human model to create more comfortable and safer work system so that the Nordic Body Map (NBM) score, work posture score assessed by using Rapid Upper Limb Assessment (RULA), and the compression force of work biomechanics can be decreased. Theoretically, some alternative size of wooden-bench manual thresher design can decrease the RULA score, from high to moderate. Practically, the new manual paddy thresher that was proposed is better optimized. The use of that tool reduces peasants’ physical workload as much as 1.47% and NBM scores as much as 7-20%.

Keywords: Work-related Musculoskeletal Disorders (WMSDs), RULA, Biomechanics, CATIA

1. Introduction

Paddy is an agricultural commodity and also a staple food for Indonesian society. There are two kinds of paddy cultivation in Indonesia. The first is paddy cultivation in paddy field that has a sufficient supply of water for its irrigation. The second is paddy cultivation in moor, garden, or dry land that has an insufficient supply of water for irrigation. In Indonesia, paddy production in paddy field tends to increase compared with paddy production in the dry land. Therefore, paddy cultivation in paddy field is chosen to be the object of this research.

The process to make paddy become rice starts with planting activities and ends with post-harvest activities. The farmer takes an important role in the whole process. In this research, the farmer that becomes the object of research is the one who only does harvesting activities and they only gave up his fate on the owner of the paddy field, they did not have the freedom to develop innovation in farming activities. They called peasant. If these peasants have a paddy field, it has an area of less than 0.5 ha. Those who have more than 0.5 ha paddy field, called modern farmer [1]. There are 4 steps in harvesting activities, which is cutting paddy stems, putting the crops into the thresher, threshing the crops, and packaging the grain.

In Nigeria, the percentage of agricultural mechanization is only 2%, while 98% of rice production is done traditionally using a sickle. Therefore, its production result is low. Traditional harvesting methods require a big number of workers as well as a long period of time [2]. The same case happens in Indonesia,
especially in Special Region of Yogyakarta Province. The observation of 38 rice production in small scale paddy field shows that 44% of them using manual method (using sickle, wooden-bench manual thresher, or pedal-thresher) and 56% of them using semi-mechanical method.

The use of high technology in paddy harvesting activities is very necessary since it can cut the number of workers needed, speed up the harvest time, improve productivity, and decrease the amount of wasted grain. However, manual harvest method is still maintained for several reasons. The first is the cost can be low if we hire cheap labors. The second is this method is still required for lands that cannot be done using a machine, such as highland that has terraced paddy fields, small size paddy fields, and muddy paddy fields. Instead of pedal thresher, a wooden-bench manual thresher is quite typically used by small-scale or grass-roots farmers in Indonesia, especially in Java Island [3] since the grass-roots farmers or peasants only have small size paddy fields and do not have target completion time.

In manual paddy harvesting activities, the whole process is done by manpower, starting from the cutting of paddy stems until the packaging of grains. The cutting of paddy stems is done by using a sickle, in which peasant is required to be in bending position. The bottom cutting technique is cutting paddy stems at the distance of about 25 cm from the lower end of the stem. Besides bending, the peasant is also required to hold the sickle with his right hand and, at the same time, hold the paddy with his left hand. After cutting the stems, all of the paddy stems are placed in one place. After that, the peasant will walk to the threshing location while carrying the stems on his head or his back. The next step is threshing the grain. One of the most popular techniques to do this is by using wooden-bench manual thresher. When peasant is about to beat the crops against a wooden board, his body posture is stand up straight. When peasant beats the crops against the wooden board, his body posture is bending while holding the crops that weighs 0.5-1 kg and has a diameter of about 10 cm. The last step of this manual rice harvesting activities is the packaging of grains, in which the grains are put into sacks.

| Sample Number | Age (years) | Weight (kg) | Height (cm) |
|---------------|-------------|-------------|-------------|
| 1             | 47          | 49.7        | 142         |
| 2             | 47          | 64.6        | 158         |
| 3             | 40          | 52          | 166         |
| 4             | 55          | 72.8        | 168         |
| 5             | 43          | 56.6        | 164         |
| 6             | 39          | 60.7        | 159         |
| 7             | 46          | 61.5        | 174         |
| 8             | 60          | 61.5        | 168         |
| 9             | 55          | 57.2        | 166         |
| 10            | 45          | 62.7        | 160         |

Paddy cultivation includes several harmful activities that require peasant to work in bad posture for a long period, no exception for the harvesting activities [4]. Peasant suffers from musculoskeletal disorders (MSDs) that causes low back pain as a result of working in a bad postures, such as bending or squat down for a long time [5]. Based on the type of occupations, the highest prevalence of MSDs is found in farmer, fisherman, and labor, with the percentage of 31.2%. This percentage will be increased as they get older [6]. MSDs are pain or injury in skeletal muscle, in which the severity of injury falls in the minor category up to severe category. If the muscle experiences static muscle loading repeatedly for a long period, it will lead to damage in joints, ligament, and tendon [7]. Work-related musculoskeletal disorders (WMSDs) are MSDs that happen due to work condition, such as work posture, repetition, heavy activities, and static muscle loading [4].

In addition to working in a bad posture for a long period, peasant also does several heavy activities that will cause fatigue as a result of a heavy workload. Different activities in paddy cultivation lead to a significant increase in heart rate, which is an indicator of physiological pressure [8]. Ergonomic
evaluation is required to make sure that the workload does not exceed peasant’s work capacity. Manual harvesting method is still needed to be maintained yet it risks peasant to suffer from health problems. Therefore, it is necessary to find a solution that enables peasant to work in a safer and more comfortable condition.

This research is conducted to minimize the risk of MSDs and physical workload of the peasant by designing tools that fit the peasant’s anthropometric. In designing the tools, this research used CATIA V5R20 software that can create and combine 3-dimensional images with a mannequin that resembles the real condition as well as show the result of biomechanical analysis. The mannequin of the digital human model has similar anthropometric properties to this study participants. That digital human model is a valid model for representing the participants because it has a posture with certain angles equals to the participants.

2. Methods

2.1. Participants
Ten peasants from Bantul and Sleman Regency, Special Region of Yogyakarta Province, Indonesia, are involved in this research, in which they will do harvesting activity using sickle and threshing activity using a manual method called wooden-bench manual thresher. The data retrieval is conducted during March-April 2019. Physical characteristics of the peasants observed in this study are heart rate used to determine the physical workload, as well as posture to determine the value of working posture and biomechanics.

The peasants involved in this study are all male whose age range from 39-60 years old. Their information are shown in Table 1. Their educational background differs from elementary to high school. As much as 60% of the peasants smoke and 70% of them consume coffee. There is only 40% of peasants that have sufficient sleep time (6-8 hours), while the rest 60% have sleep time less than 6 hours. On average, peasants work in the rice field for 9 hours, starting from 7 am until 4 pm.

2.2. Surveys of Musculoskeletal Disorders
To know the peasant’s level of pain intensity during harvesting activity, the researchers used the modification of Standardized Nordic Questionnaire (SNC) as used by Swangnetr et al (2014) [9]. This questionnaire is used to assess the peasant’s level of pain intensity when they do land preparation activities for paddy cultivation. This modification of SNC is known as Nordic Body Map questionnaire. The NBM questionnaire is a body map that helps us to know which muscle that feels pain as well as to know the level of skeletal muscle pain felt by the worker. This questionnaire enables us to compare the pain or injury level felt by different parts of the body based on its severity and to know its correlation with the worker’s ability to work [10].

NBM questionnaire divides the human body into 15 parts, starting from the neck to feet. To assess the MSDs felt by workers, this research used a 4 points Likert scale. 1 means the workers do not feel pain at all, 2 means the workers feel mild pain, 3 means the workers feel moderate pain, and 4 means the workers feel severe pain in their skeletal muscles.

2.3. Assessment of Physical Workload
The level of physical workload assessed using cardiovascular load (CVL) equations based on the measurement of heart rate while working, maximum heart rate, and resting heart rate. The measurement of heart rate can be used to know the level of fatigue felt by a person since the heart rate will be increased if the workload is increased [11].

The peasant’s heart rate is measured using the digital wrist blood pressure monitor tool (Microlife). The use of that tool is to facilitate the measurement of the peasant’s heart rate through the pulse. Heart rate measurements are conducted periodically every 1 hour from 6 am to 4 pm. The measurement result at 6 am is a resting heart rate where the farmer has not worked. While the average heart rate measurement from 7 am until 4 pm is the working heart rate.
The CVL value is obtained from the following equation:

\[
\%CVL = 100 \times \frac{(HR_{work} - HR_{rest})}{(HR_{max} - HR_{rest})}
\]  

1

HR max (for female) = 200 – age

2

HR max (for male) = 220 – age

3

In which CVL as Cardiovascular load (%), HR work as the average heart rate while working (beat/minute), HR max as maximum heart rate (beat/minute), and HR rest as resting heart rate (beat/minute).

![Figure 1. The NBM Result Before Work](image1)

![Figure 2. The NBM Result After Work](image2)

Based on CVL calculation, the classification of workload level includes the acceptable category (<30%), moderate category (30%-59%), high category (60%-99%), and no tolerance category (100%). The acceptable category does not require further action, the moderate category requires workload reduction in several months, the high category requires workload reduction in several weeks, and no tolerance category requires either workload reduction as soon as possible or the work should be stopped [12].

2.4. Work Posture

The RULA method is used to estimate body posture, especially upper body. In principle, this method measures the angle made by parts of the body while working. The measurement is divided into two groups: group A and group B. Group A include upper arm, lower arm, and wrist. Group B includes feet, torso, and neck. The RULA grand score is divided into 4 categories: score 1-2 indicates that the body posture is acceptable, score 3-4 indicates that a further investigation is needed and a modification might be necessary, score 5-6 indicates that both further investigation and modification is urgently needed, and score 7 indicates that investigation and the application of modification is very necessary [13].
2.5. Assessment of Biomechanics

Biomechanics is a study about the movements of living organisms that use mechanical laws [14]. Mechanics is the branch of physics that is related to the description of movements as well as how a certain force can create movements. Forces in living organisms can create movements that act as a beneficial stimulation for growth and development, can cause injury if the forces are too much. Biomechanics can help us to understand how living organisms move and how kinesiology can help to improve movements and make safer movements by using conceptual and mathematical calculation [15].

3. Results and Discussion

3.1. Musculoskeletal Disorders

The assessment using NBM questionnaire is conducted twice, which is before and after work. This aims to know the MSDs felt by the peasant as a result of harvesting activities. The NBM questionnaire used in this research is the one that divides parts of body into 15 parts, which are neck, left shoulder, right shoulder, upper back, left elbow, right elbow, lower back, left hand, right hand, left thigh, right thigh, left knee, right knee, left foot, and right foot.

The result of the assessment using the NBM questionnaire, which is conducted before work, shows that parts of the body that feel pain are left shoulder, right shoulder, upper back, and lower back. All of the peasants do not feel any pain in other parts of their body. The detail of the pain felt by the peasants is shown in Figure 1. The pain felt before working is caused either by congenital disease or as a result of working on the day before.

The result of assessment using the NBM questionnaire, which is conducted after work, shows that there are only two parts of peasants’ body that do not feel pain: left elbow and right elbow. Meanwhile, other parts of peasants’ body feel pain, in which the pain intensity differs from one another, as shown in Figure 2. The pain or injury is felt by the peasant who does the whole process of harvesting activities, starting from the cutting of paddy stems, the transportation, the threshing, until the packaging of grains.

Based on the result of assessment using the NBM questionnaire, we can see that the parts of the body where peasants mostly feel pain are upper back and lower back. This happens because of bad posture, which is bending during the cutting and threshing process, as shown in Figure 3. The activity of cutting and threshing is done repeatedly for 7-9 hours a day.

An experiment using a 5x5 m rice field has been conducted. Based on the experiment, a 1000 m² rice field requires 24 hours and 21 minutes for the cutting of paddy stems and 24 hours and 40 minutes for the threshing, which is done by 1 peasant. Usually, one rice field is done by 3-5 peasants. The peasants will work from 7 am to 4 pm, with an hour time off at 12 am. The task will be continued on the next day if it cannot be finished on that day.

Musculoskeletal disorders are caused by excessive biomechanical load. It is a work-related disease that affects backbone, tendon, nerves, muscles, and bloodstream system. This disorder happens due to bad posture during work, repeated pressure that happens in a long period, or excessive pressure that may happen during work [16].

3.2. CVL Physical Workload

The workload is defined as the capacity of the human body to perform a task. From the perspective of ergonomic, the workload received by a worker should be adjusted or balance with physical workload [17]. The result of the research using CVL calculation shows that 10% of peasants have an acceptable workload, 80% of peasants have a moderate workload, and 10% of peasants have a high workload. The average of peasants’ CVL percentage is 45.03%, which means it falls to the moderate workload category. This level of workload indicates that the workload should be reduced in several weeks.

A research conducted by Krause et al (1997) shows that physical workload is related to back pain and neck pain. Aside from workload, the ergonomics factor related to back pain is age, sex, height, and weight [18]. Low back pain (LBP) is to age, body mass index (BMI), smoking, work period, work posture, and workload [6].
Generally, the physical ability of the human body will be weakened as the human gets older. The aging process is marked by the decline of work ability due to changes in organs, cardiovascular system, and hormonal system [19]. Nutritional status shown by BMI is related to the health level and productivity of the workers. Good nutritional status makes the workers become more productive in performing their tasks [20].

![Figure 3. The Process of Paddy Stems Cutting and Threshing](image)

The smoking habit has a significant relationship with a muscle injury since the nicotine contained in cigarette will lessen the bloodstream that flows to the organ tissue. Aside from that, nicotine also decreased the amount of mineral in bones, so that it causes pain due to damage in the bones. The people who suffer from low back pain are mostly the one with smoking habit [6].

Bad work posture is also the cause of fatigue and muscle injury. However, most workers do not aware of that. The workers’ habit, such as sit, stand, and bend, can cause fatigue, muscle tension, and injury [21]. The injury makes the workload received by the workers’ body become even heavier.

3.3. RULA Work Posture

The posture of workers while working is assessed using the RULA method. In this research, the assessment of work posture using the RULA method is conducted with the help of CATIA V5R20 software, as shown in Figure 4. The working posture analysis is conducted based on one representative peasant where the condition is done by almost all peasants in this study, including the movement angle of each body parts. The same thing is done in the biomechanics analysis discussed in the next section.

The process of cutting paddy stems has the RULA score of 4, which means a further investigation is needed and a modification may be necessary. The process of transporting crops has the RULA score of 5, which means both further investigation and modification is urgently needed. The process of threshing has the RULA score of 6, which means both further investigation and modification is urgently needed. Meanwhile, the process of packaging has the RULA score of 3, which means a further investigation and modification may be necessary.

The process of transporting crops has the highest score since the peasant should bring heavy paddy stems, which is about 23.5 kg for each transportation process. The value of this work posture can be diminished by reducing the mass of paddy stems brought by the peasant. The process with the second highest score is threshing. The threshing process requires the peasant to be in bending position and their legs to be repeatedly bent. The high score of work posture in the threshing process needs further action, which is the redesigning of wooden-bench manual thresher by regarding the anthropometric of the peasants. Therefore, they can work in a better posture that gives no harm to their health.
One of the studied aspects of ergonomic is anthropometric. Anthropometric is a science that studies the human body, especially its size and shape. While ergonomic itself learn about workers and how they work, the equipment they use, the workplace, the psychological aspect, and the work environment. To put it simply, ergonomics can be understood as an adaptation of the occupation towards the workers [22].

One of the short term goals of ergonomic is to guarantee that the workers are safe from the risk of a work accident. Meanwhile, its long term goal is to prevent the workers suffering from work-related diseases. Unnatural movements and working posture lead to MSDs, which emerges as a long term effect of a certain job or usually called as work-related musculoskeletal disorders (WMSDs) [23].

3.4. Biomechanics
The biomechanics assessment in this research is done with the help of CATIA V5R20 software. As shown in Figure 5, there are 5 design variations of wooden-bench manual thresher and mannequin, which are labeled with code A1, A2, A3, A4, and A5. Design A1, A2, and A3 are the wooden-bench manual thresher found on the field along with the peasants that use it. Design A4 is the design of an ideal wooden-bench manual thresher according to research conducted by Syuaib (2015). Meanwhile, design A5 is the design of wooden-bench manual thresher that has been adjusted with the anthropometric of the peasant, according to the result of research that has been conducted. The five wooden-bench manual threshers and mannequin has their own sizes, as shown in Table 2.

![Figure 4. The Peasants’ Work Posture When Doing Harvesting Activities](image1)

![Figure 5. Wooden-bench Manual Thresher](image2)

**Table 2. The Dimension of Wooden-Bench Manual Thresher**

| Code | L (cm) | H (cm) | W (cm) | θ (°) |
|------|--------|--------|--------|-------|
| A1   | 92     | 59     | 99     | 40    |
| A2   | 98     | 53     | 87     | 50    |
| A3   | 84     | 58     | 78     | 52    |
| A4   | 52     | 63     | 70     | 64    |
| A5   | 68     | 69.7   | 70     | 64    |
The assessment result of biomechanics and work posture of each mannequin, which represents peasants, is shown in Table 2. Design A1 up to A4 have the RULA score of 7, which means it needs investigation and the application of modification. The moment value shows the force that works from the rotary axis. The bigger the moment value, the faster the work time yet the bigger the force required. It also means that the bigger the moment value, the greater the fatigue felt by peasants. The compression value shows how intense the compression received by peasants’ body. Compression itself means the force that works per unit area. The bigger the compression value, the greater the compression received by peasants’ body, which means the condition is bad for work. Join shear is the force required to do arm swing, while anterior shows forward movement. The design with the highest and lowest moment value and compression value are respectively A1, A2, A3, A4, and A5. The design with the highest and lowest joint shear are respectively A4, A2, A1, A3, and A5 in an anterior position.

Based on the RULA and biomechanics score (as shown in Table 3), it can be seen that the new design of wooden-bench manual thresher that has been adjusted with the assessment result of the peasants’ anthropometric has the lowest score. The initial RULA score, which is 7, is decreased to 4. The RULA score of 4 indicates that a further investigation is necessary and a modification may be needed. So does with the moment value, the compression value, and joint shear.

The new design of wooden-bench manual thresher (design A5) has the lowest moment value, compression value, and joint shear, so that the force that should be released by peasants will be smaller, the compression received by peasants’ body will be lighter, and the force needed to do arm swing will be smaller as well. These aspects make the work easier to be done so that the risk of MSDs and excessive workload can be reduced.

### 3.5. Experiment Results of New Tool Design

In its realization, the new design of paddy thresher tool has dimensions of AB length = 58 cm, AC = 70 cm, BC = 68 cm, AD = 68 cm, height of AO = 56 cm, amount of A angle = 60°, B angle = 70°, and C angle = 50° as shown in Figure 7. That tool is made with hollow galvalume material which has strong but lightweight characteristics so that is easy to carry and move. The weight of that tool is 7 kg.

The physical workload of 5 peasants when using the old tool is moderate with CVL value as much as 50.3%. While the physical workload when using the new tool is also moderate but the CVL value decreases to 49.56%. The use of new paddy thresher tool reduces peasants’ physical workload as much as 1.47%, not significantly different from physical workload on the use of old tool. Assessment with the NBM questionnaire showed that the use of a new tool can reduce NBM scores as much as 7-20%, significantly different from NBM scores on the use of old tool.

The use of a new tool can reduce RULA scores 80% of peasants from 4 to 3, while 20% of others have the same RULA score of 4. This is caused by the suitability of work equipment used to affect the posture of workers which then also affects musculoskeletal complaints [24]. From the perspective of biomechanics, the new tool is able to reduce the moment value as much as 12-57%, the compression value as much as 9-45%, and the joint shear value as much as 42-57%. The purpose of biomechanics is to improve human performance in work and reduce the risk of injury to the skeletal muscle system [23].

| Code | RULA Score | Moment (Nm) | Compression (N/m²) | Joint Shear (N) |
|------|------------|-------------|-------------------|----------------|
| A1   | 7          | 141         | 2572              | 57 anteriors   |
| A2   | 7          | 138         | 2490              | 60 anteriors   |
| A3   | 7          | 132         | 2455              | 53 anteriors   |
| A4   | 7          | 130         | 2371              | 73 anteriors   |
| A5   | 4          | 110         | 2071              | 38 anteriors   |
### 4. Conclusions
Theoretically and practically, the design of wooden-bench manual thresher that was proposed is better optimized. The use of new paddy thresher tool reduces peasants’ physical workload as much as 1.47% and NBM scores as much as 7-20%.

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