Design Conformity of Indonesian-Made Mini Rice Combine Harvester and Anthropometry of Javanese Farmers

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ABSTRACT

The combine harvester in Yogyakarta Province Special Region has a small size because it is used to harvest rice in a narrow area. The purpose of this study is to determine which parts of the mini combine harvester machine are not ergonomic and need to be improved so that the operator can work comfortably and safely. The types of mini combine harvester machines investigated in this study are QUICK H140R, TANIKAYA Ironbee HT12, and JAP001. Results showed that, for the three combine harvester machines, there was a mismatch in the physical size of the engine and the anthropometry of the operator. The main problems of the mini combine harvester machine are less ergonomic seat, inappropriate placement of the control table, hand activity in the maximum area, narrow workspace for leg movements, and less supportive footstep for the operator to work while standing. This information is expected to be utilized by Indonesian mini combine harvester machine designers so that the new design of combine harvester machines will be ergonomic, safe, and comfortable.

Keywords: anthropometry; combine harvester; maximum area

INTRODUCTION

Rice is a staple food of the Indonesian people, and the demand for rice continues to increase from year to year. In 2016, the Agriculture Ministry of Indonesia provided combine harvester machines to many regions of Indonesia to increase the productivity of rice harvest because of the large production capacity (Sulaiman, 2018). In South Sumatra, the combine harvester machine is only used when the number of harvest workers is insufficient. When the combine harvester machine is used, harvesting becomes faster and the cost of harvesting becomes cheaper (Amirullah, 2016).

The optimum interaction between humans and machines can be achieved by integrating the anthropometric data of the operator with the technical design of the machine. Ghaderi et al. (2014) designed the seat of a combine harvester on the basis of the anthropometric data of Iranian operators. The magnitude of the machine is combined with the magnitude of the vibration felt by the whole body of the operator (i.e., whole-body vibration [WBV]) when the operator sits on and operates the combine harvester machine. The condition of wetland has a strong influence on the magnitude of the vibration felt by machine operators (Almosawi et al., 2016). Exposure to WBV for at least the working time is significantly associated with musculoskeletal disorders (MSDs) of the neck and shoulder or arm of the operator (Charles et al., 2017).

Bangladesh is one of the countries that has been conducting research on the adoption of agricultural machinery by small farmers. Currently, farmers, such as those in Indonesia, use agricultural machinery through a rental system (Mottaleb et al., 2016). In other developing countries, such as Thailand, Pakistan, and India, indigenous engineers are challenged to create

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inexpensive combine harvester machines for small farmers. In India, an indigenous combine harvester has been tested and introduced to the market (Abdulkarim et al., 2017). Manabete (2014) introduced indigenous technology for sustainable development in West Africa in relation to human factors, as proposed by Adjiboloso. The Nigerian government assigned many universities to design a low-cost mini combine harvester using local materials (Abdulkarim et al., 2017).

A similar study of anthropometric measurements for the ergonomic design of students' furniture was conducted by Taifa and Desai (2017). They recommended several dimensions, such as bench depth and width, backrest, and desk height, depth, and angle, for comfort, safety, well-being, suitability, and reduced MSDs. In Iran, research on the suitability of the physical size of the combine harvester machine-operator seat for the anthropometry of the combine harvester machine-operator was conducted by Ghaderi et al. (2014). The current seat design is too high, too small, or too shallow and has unmatched armrest and backrest. Work-related risk factors for taxi drivers are imposed by prolonged periods of sitting, deviations from the neutral body alignment, repetitive motions, vibration, noise, strenuous tasks, and frequent handling of luggage. Work-related musculoskeletal disorders (WMSDs) are commonly reported by drivers of buses, trucks, and taxis (Bulduk et al., 2014). Guo et al. (2016) investigated operator seat upholstery in terms of comfort and protection of health.

Several Asian countries with a large population of people engaged in agriculture competed in designing a combine harvester by relying on their respective local wisdom. It is time for Indonesia to try to do the same thing. This study evaluates the mini combine harvester in terms of ergonomics so that the information can be used by mini combine harvester machine designers to improve the comfort and safety of mini combine harvester machine operators.

METHODS

This study was conducted over 3 months between February and April 2019 in Bantul District, Yogyakarta Province Special Region, west Indonesia. Ten mini combine harvester machines and their operators were used as research samples. The mini combine harvester machine is managed by farmer groups in 10 subdistricts in Bantul. During its operation, the mini combine harvester machine is manipulated by one operator and one helper. The mini combine harvester is used to harvest rice every day during the rice harvest season. The use of the machine is stopped during the dry season because corn is the main crop harvested at this time. Each sample is observed for 3 days during the harvest season. The harvest time usually starts at 0900 and ends at 1700, unless there is rain. Three different models of mini combine harvester are evaluated. The first machine is QUICK H140R (machine Q), which has an iron wheel. The second machine is TANIKAYA Ironbee HT12 (machine T). The third machine is JAP001 (machine J). The last two machines have rubber wheels.

RESULT AND DISCUSSION

Anthropometric Measurements

In this study, the anthropometric data of male Javanese farmers use the data presented by Syuaib (2015). The anthropometric data used for the evaluation of the ergonomics of the mini combine harvester are listed in Table 1.

Table 1 shows the average data (50th percentile), 5th percentile, and 95th percentile. For example, the distance of the lever to the control table is determined using a small sample size (i.e., 5th percentile) so that 95% of the population (i.e., small-sized operators) can comfortably use the lever, whereas only 5% of the population has difficulty using the lever. The height of the roof is determined using a large sample size (i.e., 95th percentile) so that 95% of the population can be comfortably protected from sunlight, whereas only 5% of the operators with a height exceeding 171 cm can be slightly uncomfortable. The 50th percentile denotes the median or mean.

A normal work area is formed when the upper arms are close the body and the forearms can move freely to do something. The maximum workspace is formed when both hands can stretch left and right, up and down. The optimum area is between the normal work area and the maximum workspace. A layout of the optimum and maximum areas to control upper and lower limb activities is shown in Figures 1a and 1b. The striped areas denote the optimum area. The maximum area is limited by the lines that surround the front side of the human body.

The seat has a depth (buttock–popliteal length 50th percentile) and width (hip breadth 50th percentile) of 46.7 cm × 30 cm and a height of 40 cm. The seat is equipped with foot space so that the operator's feet can move freely to eliminate fatigue. Figures 1a and 1b also show the optimum area for leg movement.

The optimum area (striped area) is the area for the hands to work at a height of about elbow level, with an average hand length (50th percentile) of 69.9 cm, which indicates the maximum distance of the hand range. Knee height is the minimum height of the control

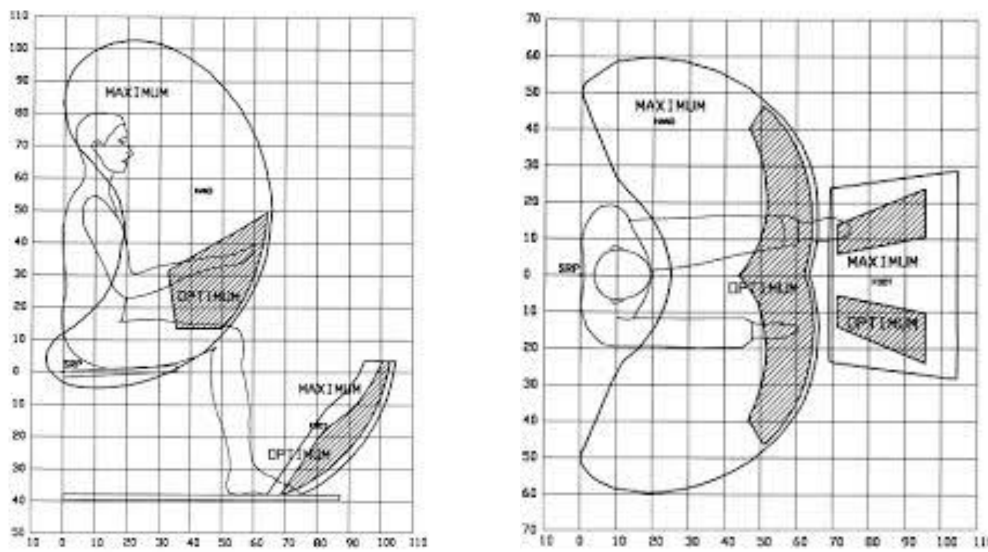
Table 1. Body measurements of male Javanese operators (Syuaib, 2015)

	Criterion	Used to evaluate	Dimension (cm)		
			Mean	5th percentile	95th percentile
1	Stature		162.0	153.0	171.1
2	Elbow height	Ergonomic height of hand to work (standing)	101.1	93.8	108.3
3	Forward grip reach	Length of the maximum workspace	69.9	62.8	77.1
4	Sitting elbow height	Ergonomic height of hand to work (sitting)	21.8	16.5	27.2
5	Sitting knee height	Knee height + allowance = minimum height of the control table	52.0	46.7	57.3
6	Buttock–knee length	Buttock–knee length + allowance = minimum length from the buttock to the control table	55.3	49.4	61.1
7	Buttock–popliteal length	Length of the seat	46.7	40.6	52.8
8	Hip breadth	Breadth of the seat	30.0	25.3	34.7
9	Forearm–hand length	Normal workspace	45.6	42.2	49.0
10	Grip diameter	Diameter of grip control lever	4.3	3.5	5.0
11	Foot length	Length of the foot	24.2	22.1	26.3
12	Foot breadth	Breadth of the footstep	10.1	9.0	11.2

table (95th percentile), which is 57.4 cm. The minimum control table layout is located in front of the worker's knees when sitting so that the buttock–knee length (50th percentile) is 55.3 cm. Figures 1a and 1b are used to compare the display layout and control of different mini combine harvester machines. These images are used to determine the seat position, control position, and hand movements on the basis of the seat reference point (or buttock reference point). A good working position is a straight neck, shoulders, and back, arms and shoulders in the resting position, elbows close to the body or slightly forward or backward, table height at about elbow level or lower, both feet on the floor, and knees forming a 90° angle when sitting (Anonymous, 2019).

Physical Measurement

In terms of physical size, the seat of the combine harvester machine has a shorter depth × width



a. Vertical workspace for the arms and legs

b. Horizontal workspace for the arms and legs

Figure 1. Workspace area for the arms and legs

compared with the anthropometric measurements of the operator. The control table is placed in front of the operator, with a table distance that is too close (i.e., −5 cm distance from the knee), which means that the knee cannot form a 90° angle because the area is too narrow, and the buttock–knee length is longer than the buttock–control table distance. For all three machines, the operator cannot sit with knees forming a 90° angle. All operators manipulate the machine by moving the control lever to the maximum workspace. Some control levers have small grip dimensions, whereas others are larger than standard grips. On machine J, the footstep used to operate the machine in the standing position is too narrow; thus, the operator cannot change the position of his foot when standing. In the standing position, the operator needs to remove the seat to reach the footstep. Moreover, the footstep is located far behind the machine; thus, the operator needs to bend his body to reach the control lever.

Profile of the Operators

Three types of mini combine harvester machine are selected. The machine and operator are sampled only once. All operators are male farmers. The operators are aged between 23 years and 60 years, with the average age of 45 years. The operators attained primary school to senior high school education. All operators are married, and nearly all are smokers and coffee drinkers. None of the operators had mechanical or automotive education. Moreover, none of the operators received training on combine harvester machine maintenance. The mean height of the 10 mini combine harvester machine operators is 168.2 ± 6.7 cm. The profile of the mini combine harvester machine operators is presented in Table 2.

In terms of the body mass index of the operators, 50% had a normal body weight and 30% was overweight. The operational physical workload is described by the cardiovascular load (CVL), with 60% of the operators exhibiting a CVL score less than 30, which indicates that the operator is not tired, and 40% of the operators needing improvement in their work systems so that they do not feel tired when working. However, the operator physical workload is generally low in terms of heart rate. The mental workload of the mini combine harvester machine operator is at a moderate level of 80%.

The operator physical workload measured from the heart rate and CVL is at the low–medium level, and the mental load is at the medium level. This reduction in physical and mental workload is expected to occur if physical improvements to the mini combine harvester machine are designed so that the operator can work more safely and comfortably.

The operator’s work physiology is described as the change in the operator’s heart rate. The highest heart rate for the three machine operators has nearly the same pattern. The highest heart rate is observed at 11 am, which means that it is time for the operator to rest. However, this heart rate is strongly influenced by stress and environmental conditions (Yassierli and Iridiastadi, 2014).

Profile of the Machines

The lowest vibration was observed in machine T, followed by machine J. Meanwhile, the highest vibration was observed in machine Q. High vibrations cause annoying noise. The lowest engine noise was observed in machine J, followed by machine T. Meanwhile, the highest engine noise was observed in machine Q. The high vibration and noise observed in machine Q can be attributed to its iron wheel. By contrast, the other machines have rubber wheels (Table 3).

Table 2. Profile of the mini combine harvester machine operators

	Parameter		Data	% samples for criteria score		
				Low	Medium	High
1	Age	years	23–60	–	–	–
2	Experience	years	1–3	–	–	–
3	Educational attainment	–	Elementary to senior high school	–	–	–
4	Body mass index	kg/m^2	21.9 ± 3.25	20	50	30
5	Cardiovascular load		20.9 ± 9.3	60	40	0
6	Heart rate	beats/min	95.10 ± 7.43	0	100	0
7	Mental workload	–	68.39 ± 11.67	10	80	10

Table 3. Profile of the mini combine harvester

	Parameter		Data	Order of the parameter values
1	Vibration	mm/s^2	24.5 ± 11.2	T < J < Q
2	Noise	dB	98.56 ± 3.65	J < T < Q

The performance of the mini combine harvester machines was evaluated in terms of vibration and noise categories. Noise has become a common problem in human–machine systems. Noise can be distracting, complicate communication, cause fatigue, reduce efficiency, and permanently reduce hearing ability (Sumer et al., 2006).

Mini combine harvester QUICK H140R: This machine is operated only in the seated position as there is no facility available for operating in the standing position. The seat is made of soft material, but its size is smaller (33 cm × 33 cm) than the anthropometric buttock–popliteal length and hip breadth (42.7 cm × 30 cm). The height of the seat is nearly the same as that of the control table. From the anthropometric measurements, the buttock–knee length of the operator is 55.5 cm, but the physical length is only 50 cm. The feet go straight down to the iron, which acts as footstep. The knees cannot form a 90° angle because the area is too narrow. The thigh and knee point downward under the control table. The working area of the hand is in the maximum area, which is below the elbow level. The lever diameter is 2–3.5 cm, which is smaller than the size of the hand-grip.

Mini combine harvester TANIKAYA Ironbee HT12: This machine can be operated in the standing or sitting position. The seat is made of fiber, large, and tall. For the average-sized operator, his feet will hang; thus, the sitting position will be uncomfortable for him when manipulating the machine. However, the workspace is wide enough so that the operator's feet can move freely. The control table is in the maximum area, and its height is about elbow level. When the operator works while standing, the control lever is in the maximum area. The chair is only utilized for resting.

Mini combine harvester JAP001: This machine can be operated in the standing or sitting position. The seat is round and made of removable green fiber. There is a narrow engine floor for the feet when operating the machine while seated, and the knee lane is <90°. The control table and short levers are at the end of the harvester without any allowance. The footstep at the bottom of the seat is used when operating the machine while standing. However, the seat needs to be removed so that the operator can reach the footstep. The footstep size is small, i.e., at least 24.2 cm × 20.2 cm. The footstep is only 22 cm from the ground, causing it to touch the ground when the mini combine harvester machine swings across uneven ground. When standing, the distance from the hand grip to the control table is relatively far that the operator must bend down to reach the lever. Thus, the operator works slightly bent at a height of about elbow level in the maximum area.

DISCUSSION

Profile of the Operators and Machines

The concept of mental workload is important with the increasing semiautomatic technology on various tools and machines. Semiautomatic machines require processing information that needs human mental abilities, particularly analytical skills. At present, the concept of mental workload is more important than the concept of physical workload (Hacker, 2013). One of the tools used for mental load analysis is the NASA Task Load Index. However, this method is subjective. Workers are asked to assess six aspects, namely, mental demand, physical demand, temporal demand, effort, performance, and frustration levels (Iridiastadi and Yassierli, 2014). Mental workload in statistical calculations is included in the medium category (with the value of 51–79), with variants that are not significantly different between operators.

By causing vibrations, bending will significantly cause MSDs of the shoulders and neck. Sitting for a long period of time without backrest will also to cause pain in the shoulders and neck (Chandrasekaran et al., 2003). Noise is a factor that distracts the operator, causing the operator to become less careful and more tired, affecting work capacity, and ultimately reducing the safety limits of work (Sumer et al., 2006). According to the Ministry of Health Regulation on Environmental Health Standards and Requirements, for industrial work, the operator is exposed to vibrations for 8 h of work, so the maximum allowable vibration is 5 m/s^2.

High vibration will cause noise. The maximum noise allowed for operators who work 8 h/day is 85 dB (Anonymous, 2016). Engine performance can be improved by reducing vibration and noise, which is quite distracting. Noise can be reduced by installing a cab on the combine harvester machine. Noise exposure can also be reduced by using ear protection equipment.

MSDs are likely to increase by up to five times if the operator is exposed to WBV and noise from the combine harvester machine and performs lifting, bending, and rotating activities (Charles et al., 2017). According to the US Bureau of Labor Statistics, MSDs occurred as much as 32% from all injuries and cases of pain in full-time workers in 2014. These statistics show that MSDs are one of the most significant problems in the USA (Charles et al., 2017). Exposure risks to MSDs were high or very high in taxi drivers (Bulduk et al., 2014). Noise exposure in four parts of East Carolina University, Greenville, NC, USA, according to the OSHA (Occupational Safety and Health Administration) and NIOSH National Institute for Occupational Safety and Health) standards is 83.0 ± 9.6 and 88.0 ± 6.7 dBA, respectively. Efforts to reduce the risk of noise exposure include changing the worker's schedule so that the level of noise exposure decreases, thereby reducing the risk of hearing loss. A previous study evaluated different tools used and noise exposure exceeding 85 or 90 dBA (Balanay et al., 2016)

Conformities Between Physical Dimension and Anthropometry

For the mini combine harvester QUICK H140R, the seat dimension did not match the anthropometric buttock–popliteal length and hip breadth. There is no workspace for leg movements. In the sitting position, the control lever is too far and too low. For the mini combine harvester TANIKAYA Ironbee HT12, the seat is only used for resting. When operating the machine in the standing position, the lever is slightly above elbow level. There is a wide workspace for leg movements. For the mini combine harvester JAP001, the seat dimension is small. The height of the control lever is about elbow level, and the distance of the lever is ideal. All hand activities are in the maximum area.

The ideal seat for the mini combine harvester machine has a length of 46.1 cm and a width of 30 cm and is made of soft and comfortable material. Moreover, the position of the seat can be adjusted. Facilities for working while standing and workspace are required on all machines. All hand activities need to be in the optimum workspace.

In this study, the control table and control lever are positioned slightly lower than elbow level. In this layout, the control table and control lever are close to the normal area and do not exceed the maximum area. This can reduce the risk of MSDs of the shoulders and neck (Charles et al., 2017). New machine designs must consider the layout of the control table and control lever when used by different operators. Minor adjustments in the seat position and control length should be made according to the operators' comfort.

The standing position is the preferred position of the operator. The mini combine harvester QUICK H140R does not allow the operator to stand up. The mini combine harvester TANIKAYA Ironbee HT12 allows the operator to stand all of the time, supported by a roof and a wide workspace. In the mini combine harvester JAP001, the footstep is near the ground, which causes it to touch the ground when the machine goes through uneven surfaces. All of the three mini combine harvester machines need a footstep to rest the foot of the operator.

Ergonomic risk factors are risks to workers that are closely related to MSDs that occur because of continuous, repetitive work on poor posture (Susanto et al., 2017). When the harvester works, MSDs occur because of repetitive and rapid movements and heavy workloads. Symptoms of MSDs include discomfort and pain in the shoulders, neck, elbows, hands, fingers, thighs, and knees. Physical work capacity is the body's ability to produce energy and obtain oxygen and is a function of the availability of nutrients and the amount of energy needed by the body to live and move (Charles, 2017).

The operator's work position can only be either sitting or standing. The operator also needs adequate footstep and workspace to reduce foot fatigue when working. Sedentary work positions, repetitive movements, and insufficient time to recover are the causes of WMSDs (Anonymous, 2018). Ergonomic posture is a work posture that involves minimum static muscle work, easy and natural hand movements, posture changes, and minimum muscular effort to maintain one posture. Harvesting rice involves working in a static position, such as bending, for a long period of time, which can cause pain and lead to disorders of the musculoskeletal system (i.e., WMSDs).

The musculoskeletal system is composed of the bones of the skeleton, muscles, cartilage, tendons, ligaments, joints, and other connective tissues that support and bind tissues and organs together. The musculoskeletal system supports, stabilizes, and regulates the movements of the body, such as walking, standing, sitting, maintaining certain attitudes and positions, and producing heat (Iridiastadi and Yassierli, 2014). Some types of work require certain attitudes and positions that are sometimes uncomfortable; thus, workers get tired quickly. Some ergonomic considerations include reducing bending over a long period of time. The movements of operators need to be in the normal range and not reach the maximum. Moreover, the working time of the operator needs to be reduced and the arm position of the operator needs to be at the normal elbow level (Anonymous, 2019).

The incompatibility of the operator's anthropometric measurements with the physical size of the machine-operator interface has an impact on the nonoptimal human–machine system; thus, the operator will be uncomfortable when operating the machine. The main problems of the mini combine harvester machine are less ergonomic seat (machines T and J), inappropriate placement of the control table (machine Q), hand activity in the maximum area (machines Q, T, and J), narrow workspace for leg movements (machines Q and J), and less supportive footstep for the operator to work while standing (machines Q and J). This information is expected to be utilized by Indonesian mini combine harvester machine designers so that the new design of combine harvester machines will be ergonomic, safe, and comfortable.

CONCLUSIONS

The Indonesian mini rice combine harvester needs to be improved in terms of physical size on the basis of the anthropometry of the operator. The main problems of the mini combine harvester machine are less ergonomic seat, inappropriate placement of the control table, hand activity in the maximum area, narrow workspace for leg movements, and less supportive footstep for the operator to work while standing. This information is expected to be utilized by Indonesian mini combine harvester machine designers so that the new design of combine harvester machines will be ergonomic, safe, and comfortable.

CONFLICT OF INTEREST

There is no conflict of interest between the author and other parties regarding this research.

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