Design of Harvesting Tool Using Ergonomic Approach for Musculoskeletal Discomfort Prevention in Low-Cost Farming System: A Case Study of Korean Melon (*Cucumis melo* var. Makuwa)

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Abstract. The Korean melon greenhouse applied fully involved workers (manual production) during fruit harvesting. The incorrect postures during this process cause permanent damage to body tissues, such as musculoskeletal disorders (MSDs). The results showed that workers harvesting the Korean melon fruits at the lower position are exposed to the risk of work-related MSDs. The method used the Ovako Working Posture Analysis System (OWAS) and Rapid Upper Limb Assessment (RULA). The harvesting procedure was divided into 4 activities; cutting the melon (H1), collecting the melon into a basket (H2), lifting the basket (H3), and moving forward around the plant (H4). The OWAS and RULA scores were 4 and 7, respectively. Therefore, the harvesting procedure has a high risk, which should be investigated and immediately improved. A tool design was proposed based on the ergonomic problem to obtain the appropriate posture during harvest. Furthermore, the design was consistent with anthropometry data and Korean melon's physical characteristics. As a result, the size of the harvesting tool height while standing is 73.8 cm; handle length is 9.5 cm; handle diameter is 5.0 cm; scissor length is 8.33 cm; length between scissor and basket is 16.46; length and width and height of the tool basket is 16.58 cm, 8.83 cm, and 8.83 cm, respectively.

Keywords: design · ergonomic · greenhouse · harvesting tool · musculoskeletal disorder · Korean melon

1 Introduction

The global population increases the need for more food, and deforestation occurs due to high demand for settlements. As a result, the farming area needs to be manipulated to produce crops, vegetables, and fruits to support the world's population. Crop production is increasingly threatened by unusual weather conditions, water scarcity, and insufficient land availability [1]. Currently, horizontal or vertical farming uses a plant factory system with artificial intelligence for the efficient production of food. However, a high cost is

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required to provide adequate production from this plant factory. Other indoor farming systems require lower-cost investment to build plant factories called greenhouse [2] with lesser productivity [3].

Plant factories and greenhouses have introduced their manual production systems that use only human labor as workers in removing old leaves, training and lowering stems, as well as harvesting fruit [4]. Kee et al. [5] stated that manual handling of material using body strength, incorrect posture, and "forced" work methods causes permanent damage to body tissues such as work-related musculoskeletal disorders (WMSDs). Employees sometimes work according to the characteristics of the demanding job and the non-ergonomic design of the workstation [6]. Bintang and Dewi [7] stated that when the posture is excellent and ergonomic, it is ascertained that the results obtained from the workers are also good. However, when the operator's work posture is wrong or not ergonomic, the worker will quickly get tired, leading to bone deformities. Therefore, MSDs are the most prevalent problems that threaten the health and quality of life of farmers. MSDs were exacerbated by poor ergonomic working conditions such as lifting heavy objects, repetitive movements, and difficult working conditions [8].

Several observational methods are used to assess the WMSDs applied in the industries, such as Novel Ergonomic Posture Assessment (NERPA), the Ovako Working Posture Analysis System (OWAS), Loading on the Upper Body Assessment (LUBA), Rapid Entire Body Assessment (REBA), and Rapid Upper Limb Assessment (RULA) [5, 9]. However, the OWAS and RULA are the suitable methods used to evaluate the postural stress that occurs in a person while working at the greenhouse. OWAS and RULA were applied to improve workers' conditions in the workplace, hence, continually improving performance within the proper arrangement [10, 11]. Yet, due to study evaluation, these methods are rarely observed in assessing improper work posture, which has been incorporated into ergonomic design tools for greenhouse workers.

Korean melon greenhouse (7°42′32.1″S 110°22′41.7″E, Hidroponik untuk Pesantren, Yogyakarta, Indonesia) is chosen as a case in this study. This greenhouse specifically produces controlled Korean melons that grow vertically but bears fruits at the bottom [12]. In general, Widyanti [13] revealed that Indonesian agriculture is in a poor ergonomics condition and is associated with high musculoskeletal symptoms. Therefore, improper working posture is required while treating (pruning, harvesting, cleaning, etc.) the plant. Korean melon is a high prospect commercial product due to its high nutritional value, pleasant flavor, and exotic appearance [14–16]. Liu et al. [17] characterized the plant as an oriental fruit with golden accession, brief growth period for the plant and fruit, slim pericarp, solid stem hair, small fruit, seed, and intermediate shelf-life.

The selected greenhouse was a low-cost investment plant factory, which requires postural stress from the worker to produce fruits and vegetables. Therefore, an ergonomic tool design is also proposed to assist greenhouse workers in handling food products in the lower position. The conceptual outline of this research can be seen in Fig. 1. Several studies of ergonomic harvesting tool design in agriculture production have been reported, such as for paddy [18], palm oil [19, 20], chili peppers [21], coffee [22], and orange [23]. However, the application of the ergonomic evaluation to the design of low-cost Korean melon harvesting tools has not been implemented in practice. Therefore, findings from

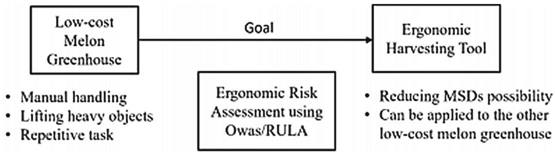

Fig. 1. Conceptual outline of the research.

this study may provide a pilot project for the harvesting tool design for the other low-cost Korean melon greenhouse, particularly in Indonesia.

2 Material and Method

2.1 Procedures and Participants

The research was conducted by directly observing the selected Korean Melon greenhouse. Chiasson et al. [24] stated that direct observation methods have the most reliable result for assessing MSDs risk, instead survey scales and systematic observations. It was appropriate to be applied in the all types of greenhouses in Indonesia because the harvesting process is still at a manual level. The phenom implies that all work was performed without any machinery aid, thus the observation of the whole body was necessary to adequately assess MSDs risk. Although the number of workers is no more than 5 people, this greenhouse has a harvesting program for hundreds of visitors every year. Therefore, it is necessary to assess work posture using the OWAS and RULA methods to measure work risks in each harvesting activity [7]. The scoring results using the OWAS and RULA methods determine posture that causes injury to MSDs. To reduce the risk of this injury, an improvement in ergonomic work aid design is proposed to reduce the risk of this injury. Withal, the ergonomic design of the harvesting tool is based on the workers' body anthropometry [7]. Therefore, the tools are expected to ease the burden on workers.

Prior to the experiment, the participants were informed of the research purpose and procedure. In this study, all greenhouse workers participated and they were right-handed ($n = 5$). Direct observation and data collection were conducted for a day. The working posture during harvesting for each participant was directly assessed by researchers to minimize bias and subjective judgment. If a high work risk value is obtained, it is necessary to improve the Korean melon harvesting process. Accordingly, the data will be a reference for researchers to propose a design for the development of an ergonomic Korean melon harvesting tool. In addition, the design of the tool specifications will be adjusted to the physical characteristics of Korean melons and anthropometric data. However, if the risk level is low, there is no need for improvement to the work element. Nevertheless, based on prior research with the same object in different countries, it was found the harvesting melon process is one of the main causes of MSDs.

2.2 Ergonomic approach

This study was conducted in a greenhouse that produces commercial Korean melons. The examined factors were workers' comfort and fatigue (pain) while cleaning plants and harvesting the fruits. Furthermore, the method used to analyze the working posture was OWAS and RULA.

2.2.1 OWAS Method

The procedure for applying OWAS consisted of making observations of the work tasks, codifying the postures, assigning risk categories, and proposing corrective actions [25]. OWAS verifies the safety level of the most common work postures for the back (four postures), arms (three postures), and legs (seven postures), as well as the weight of the load handled (three categories). The next is to analyze and assess the work posture to know the shape while performing activities using the OWAS method. In this case, Brandl et al. [26] described the OWAS classification as follows;

1) Back posture: straight, bent, twisted, or tilted to the side, bent and twisted, or bent forward and sideways.
2) Arm attitude: both arms are under the shoulder, and one of them is at or above the shoulder, they are at or above the shoulder.
3) Legs position: sitting, standing on both straight legs, on one straight leg, on both legs with bent knees, on one leg, kneeling on one or both knees, walking.
4) Load weight: less than 10 kg ($W = 10$ kg), 10 kg – 20 kg (10 kg $<$ W 20 kg), greater than 20 kg ($W > 20$ kg)

2.2.2 RULA Method

Upper limbs, primarily arms, and wrist postures were assessed using the RULA score sheet. The range of movement of each part of the body is divided into several sections (Ansari & Sheikh, 2014). The RULA was developed to rapidly evaluate the exposure of individual workers to ergonomic risk factors associated with upper extremity WMSDs [28]. The RULA ergonomic assessment tool considers biomechanical and postural load requirements of job tasks/demands on the neck, trunk, and upper extremities. Lynn and Corlett [29] stated the stages of RULA analysis as follows:

1) Group A score assessment: Group A's posture consists of the upper arm, lower arm, wrist, and wrist twist
2) Group B score assessment: Group B's posture consists of the neck, trunk, and legs.
3) Load and activity score
4) Grand score RULA
5) Interpretation of grand score: This shows the need for more in-depth analysis and provides methods for prioritizing work that needs to be further analyzed.

The RULA score is divided into 7 points and each section is scored. If the range of movement or work posture is scored as 1, it means the risk factors present are minimal. The more extreme postures are assigned higher scores will indicate an increasing presence of risk factors. The risk level of RULA was divided into four categories, i.e., negligible (1), low (2), medium (3), and high (4).

The scoring results from the OWAS and RULA methods determine the posture that causes MSDs [30]. To reduce the risk of this injury, an improvement in ergonomic work aid design is proposed. The ergonomic tool design is based on the anthropometry of workers' bodies generated by Syuaib [31]. Accordingly, Pheasant and Haslegrave [32] stated that every ergonomic design should be based on the physical and attitude of the users themselves. The aids are expected to help ease the burden on workers. Subsequently, the anthropometry of workers is measured to obtain length and width data of particular body parts to be adjusted to the design of the harvesting tool for Korean melons to be made. This implies the harvesting tool design can meet the workers' needs.

2.3 Design Process of Korean Melon Harvesting Tool

The harvesting tool design of Korean melon was made by giving attention to the product's physical characteristics and the workers' anthropometry. The products' characteristics were measured by fruit's weight, width, and length diameter. Furthermore, the worker's anthropometry was obtained from secondary data that is assumed the worker in normal condition, and the design that we made can be applied in another greenhouse. The postures that we were concerned about were shoulder breadth, standing elbow height, grip circumference diameter, and fingertip height. The 2D design of the Korean melon harvesting tool was made using graphical editor software (CorelDRAW X4, Corel, Ontario, Canada). This design provides the detailed size as we determined previously. Then, the 3D design was made using Catia (V5R18, Dassault Systèmes, Vélizy-Villacoublay, France) for the ease of visualization [33]. This software has already been performed by many researchers to make an ergonomic tool design for agricultural or industrial production, for instance, hand trowel design development for the workers in agricultural production areas [34], and harvesting tool design for palm oil [19].

3 Result and Discussion

3.1 Korean Melon Harvesting Procedure

The melon greenhouse is one of the agricultural production systems that require postural assessment because the majority of the production process is still using manual handling. It has been proven by other studies that have focused on postural evaluation in the melon greenhouse [35–37]. However, no study has been found on illustrating the proper harvesting tool design to improve the comfort in work activities. Therefore, this study not only focuses on implementing the OWAS and RULA method to evaluate the potential risk of WMSDs at the melon greenhouse, but also proposes the best design of the harvesting tool. Harvesting is defined as the procedure of gathering crops from the fields and putting the crops to secure sites for storage, processing, and consumption [36]. In this study, the harvesting process of Korean melon consists of several activities as follows (Fig. 2), cutting the melon (H1), collecting the melon into a basket (H2), lifting the basket (H3), and moving forward around the plants (H4). Furthermore, the plants have been grown in controlled conditions as stated by Shin et al. [12]. Since it bears fruits in the lower part, workers need to squat while cutting the melon and lift the basket.

The squat position is one of the high-risk postural for workers while doing their job [43]. Lim et al. [38] suggested that squatting posture needs to determine the spinal load, especially twisting, the lateral bending moment in evaluating musculoskeletal workload. Figure 2 shows the position of workers while harvesting Korean melon and the degree of discomfort at work. It also shows that workers have inappropriate positions that lead to a potential risk of WMSDs. According to NG [37], harvesting activities put high stress on the lower back during awkward postures, particularly for tree height below 3.4 m. Nonetheless, Benos et al. [36] also reported that harvesting is the most common agricultural activity of the manual operation causing MSDs. Therefore, this study concludes, in small farms or greenhouses of horticultural crops (fruits, vegetables, etc.), minimal mechanization takes place that may lead to several WMSDs especially in developing countries.

As previously stated, apart from workers, number of visitors can also pick their Korean melon. Through several direct interviews in the field, both with workers and visitors, mentioned that they experienced pain in the back, arms, and legs when plucking throughout the greenhouse area. Especially for visitors who are over 40 years old will experience many difficulties. Kim [39] surveyed 94 melon farmers in Korea using a risk assessment questionnaire. Through the survey, as many as 80.9% of farmers experienced symptoms of MSDs and 60.6% experienced symptoms of MSDs above the national institute for occupational safety and health (NIOSH) standard. The main body parts that are symptomatic are the back, knees, and arms. The main cause of this risk is due to the elements of lifting work, bending posture, and repetitive hand movements. Although the survey has been conducted, the characteristics of farmers in Korea and Indonesia are different. As stated by Benos et al. [36], ergonomic changes may be beneficial in certain countries, while the same changes may cause additional MSDs for workers due to different anthropometric characteristics in other countries. Therefore, the working posture of the greenhouse workers, particularly in the study case in Indonesia needs to be identified through OWAS and RULA.

Several studies explained that picking in the squat position is a major problem that can cause various MSDs during harvesting activities [3, 40]. According to Pinzke and Lavesson [41], one way to reduce MSDs is to set the picking position parallel to the worker in a standing position. This can be done by using a pot that is placed on a table board. However, this is difficult to apply to Korean melon cultivation because Korean melon uses a drip irrigation system. Therefore, using a table or board is likely to inhibit the flow of water. This phenom is related to the volume of irrigation that affects the growth of Korean melon plants. Manh and Wang [42] explained that increasing water availability can increase plant height, leaf area, and biomass weight of melon plants. In addition, planting Korean melon without using a table board is more common in Indonesia because it does not require additional costs. As a result, it can be assumed that the ease of harvesting procedure using the proposed tool in this study can be implemented easily by workers.

3.1.1 OWAS Analysis on the Working Posture of Greenhouse Workers

The OWAS is a survey method used to identify occupational risks that can harm humans [43]. According to Table 1, a score was assigned on each element performed during harvesting based on data collected, as well as derived from the OWAS assessment guideline performed by De Faria Silva et al. [44]. The activity of cutting the melon from plants

Fig. 2. Worker position while harvesting Korean melon (a) cutting the melon; (b) collecting the melon into the basket; (c) lifting the basket, and (d) moving forward around the plant.

(H1), the activity of collecting the melon into a basket (H2), and the activity of lifting the basket (H3), are indicated at a high-risk group due to those activities resulting in the OWAS score of 4 [45]. A score of 4 was obtained because the back is bent and slightly twisted (bent and twisted), both arms are under the shoulders, the knee is kneeling, and the load is less than 10 kg as can be seen in Fig. 2.

Meanwhile, the activity of moving forward around the plant (H4) has a score of 1 because the back is straight, the arms are under the shoulders, the legs are in a state of walking to move from one fruit to another, and the load is less than 10 kg. The OWAS score of 1 is indicated a normal posture [45]. However, sometimes the visitor or the farmer conducted the H4 by squatting while moving forward around the plant that is leading to the OWAS score of 4. It can be concluded that the Korean melon harvesting activity is included in the category of risky work.

These OWAS results are similar to the previous research conducted by Gómez-Galán et al. [46] about the assessment of postural load during melon cultivation in the greenhouse as well. The analysis showed that several postures were assessed as risk category 4, which is classified as the most harmful. The highest rate of adopted postures with this risk is observed in melon harvesting. Thence, the corrective actions need to

Table 1. OWAS score activity.

Work Element Code	Score				Category	Meaning	Action
	Back	Arm	Leg	Load Weight			
H1	4	1	5	1	4		Required immediately
H2	4	1	5	1	4	High-risk group	
H3	4	3	5	1	4		
H4	1	1	6	1	1	Normal posture	Not required

Harvesting procedure; The activity of cutting the Korean melon from plant (H1), the activity of collecting the melon into a basket (H2), and the activity of lifting the basket (H3), and the activity of moving forward around the plant (H4).

be implemented as soon as possible. However, the study of improvement postures in Korean melon harvesting has not been reported yet.

3.1.2 RULA Analysis on the Working Posture of Greenhouse Workers.

RULA was used due to the obtained results being more detailed in body measurements, specifically the upper part [47], and also become the best method for assessing postural loads [25, 48]. Eventually, RULA scores were shown in Table 2 derived from the RULA assessment guideline highlighted by Dwyer et al. [49]. As a result, H1, H2, and H3 have a RULA score of 7, which means the work is indicated at a high-risk of MSDs on the workers' whole body (upper arm, lower arm, wrist, neck, trunk, legs). Furthermore, H4 has a score of 6, which means the work is at high risk of MSDs on the workers' wrists. These results corresponded with the research of Gómez-Galán et al. [50] which observed that 65% of the postures of melon farmers have a very-high-risk level and no posture is found with low risk through RULA analysis. Therefore, the corrective action should be implemented immediately.

Consequently, OWAS and RULA were used to obtain a comprehensive observation of working posture at Korean melon greenhouse. Based on the observation with the OWAS and RULA methods, it was concluded that most of the working posture during the harvesting process of Korean melon is categorized at high risk, which means the activities must be investigated and changed as soon as possible.

3.2 Design Process

Through the analysis of physical characteristics shown in Table 3, the Korean melon has an average weight of 383.56 g, width diameter of 7.19 cm, and length diameter of 13.46 cm, which is included within the interval size as described by Liu et al. [17]. Table 4 contains anthropometry data generated from Syuaib [31], which was obtained from the farmworkers on Java island (similar circumstances in this study) as secondary data. The size determination of the harvesting tool design used in this study is provided in

Table 2. Rula score activity.

Work Element Code	RULA Score	Risk Level	Action
H1	7	High	Investigate and change immediately
H2	7	High	Investigate and change immediately
H3	7	High	Investigate and change immediately
H4	6	High	Investigate further and change soon

Harvesting procedure; The activity of cutting the Korean melon from plant (H1), the activity of collecting the melon into a basket (H2), and the activity of lifting the basket (H3), and the activity of moving forward around the plant (H4).

Table 3. Physical analysis of Korean melon ($n = 14$).

Physics Analysis	Mean	SD	Max.	Min.
Weight (g)	383.56	89.96	533.3	240.73
Wide Diameter (cm)	7.19	0.39	7.83	6.55
Length Diameter (cm)	13.46	1.48	15.58	10.72

Table 4. Anthropometry data of Java island farmworkers [31].

Body part	Mean (cm)	SD	P_5	P_{95}
Standing elbow height	101.1	4.4	93.8	108.3
Grip diameter	4.3	0.4	3.6	5.0
Hand breadth	8.3	0.7	7.1	9.5

Total sample of 371 male and female farmworkers from three different regions (west, central and east) of Java Island, Indonesia. SD = Standard Deviation.

Table 5. The 5% percentile is used to determine the holding height of the harvesting tool while in the stand position. It is aimed to make the tall workers feel comfortable when using the tool. Meanwhile, the 95% percentile is used to make the workers with a small or big body can use this tool comfortably as well.

In this study, Fig. 3 shows the proposed design of the Korean melon harvesting tool. The new design features offer user-friendly handles and height adjustability and flexibility according to the user. It was also designed for easy to use or handle, without any complex mechanical operation required and no special training required. As reported by Nurdin [18], there are 9 consumer labor attributes in the design of harvesting machines in the case study of rice, including portability, multifunction, ergonomics, lightweight, and easy maintenance. In this study, the harvesting tool height is determined by subtracting the plant pot height (20 cm) from the body proportions at elbow height while standing. Through these measurements, the height of the designed tool is 73.8 cm. The size of the

Table 5. Size determination of the tool design.

No		Specification	Body dimension	Percentile	Size (cm)
1		Length of harvesting tool	Standing elbow height	5%	73.8
2		Handle length	Hand breadth	95%	9.5
3		Handle diameter	Grip diameter	95%	5.0
4		Length × width × height of tool basket	Diameter of fruits*	-	16.58 × 8.83 × 8.83
5		Scissor length	Width diameter of fruits*	-	8.83
6		Length between scissor and basket	Length diameter of fruits*	-	16.58

* The largest size from physical characteristics is applied with an allowance of 1 cm.

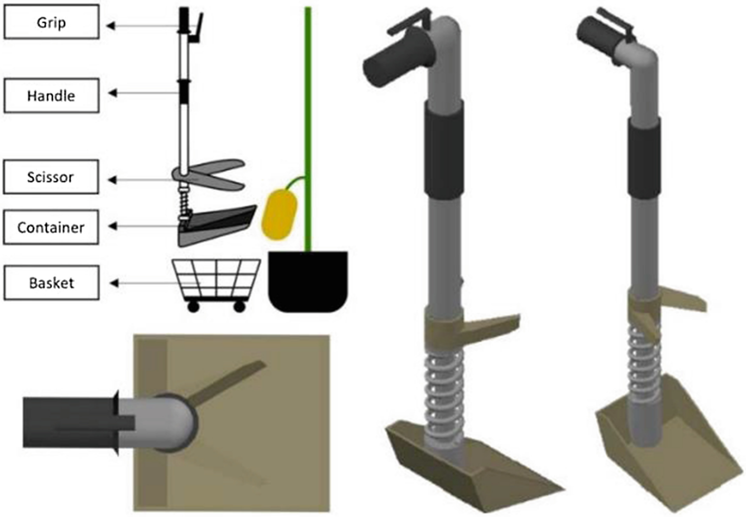

Fig. 3. Design of Korean melon harvesting tool.

scissors, the tool container, and the distance between the scissor and container of the tool were determined using the Korean melon fruit's dimensions (the length and width of the fruit diameter). The largest size was used plus a 1 cm as an allowance to allow the tool to cover the size below it. In addition, the maximum fruit weight that can be lifted using the basket is around 1000 g. Soon, this design can be made into the real one, to help the Korean melon farmer while harvesting the fruit, as well as to prevent any MSDs possibility. Further studies are expected to test the tool performance and its impact in the field to follow the success of the previous studies such as the chili harvesting device [21], harvesting tool of orange [23], as well as the ergonomic design of the bag as a substitute for a basket strapped to the waist in coffee harvesting [22], which can increase harvesting productivity and the worker's comfort.

4 Conclusions

The risk of harvesting Korean melon is categorized as a high level with OWAS and RULA analyses that need to be improved. Therefore, this study proposed a design based on the anthropometric data and physical characteristics of the Korean melon. As a result, the size of the harvesting tool length is 73.8 cm, the handle length is 9.5 cm, the handle diameter is 5.0 cm, the scissor length is 8.83 cm, the length between scissor and basket is 16.58, length × width × height of the tool basket is 16.58 cm × 8.83 cm × 8.83 cm. The study findings and future studies aimed to help create the appropriate harvesting tool for the Korean melon semi-greenhouse to reduce such loads, with the primary goal of reducing MSD risk.

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