Ergonomic of the manual harvesting tasks of oil-palm plantation in Indonesia based on anthropometric, postures and work motions analyses

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Abstract: Harvesting is the most important but burdensome work in oil-palm industries in which done manually by human power and skill. This research deals with analyses of anthropometry, work motion and posture on the harvesting tasks in the aims to understand ergonomic risks associated with the tasks and intervention needed in order to minimize the risks. A set of forty-two anthropometric dimensions and video records of work-motions were collected from a total sample of 141 male harvesting-workers from three different regions in Sumatera, Kalimantan and Sulawesi islands of Indonesia. The stature, height of eye and shoulder, and the length of arms were observed as the most relevant and critical anthropometry in designing the harvesting task and tool; and the height of the palm tree should be fully considered as well. Motion analysis revealed that the push-cutting technique with a “dodos” (a chisel-like) tool effectively applied to harvest fresh fruit bunch (FFB) which height is less than 3 m, while the pull-cutting technique with an ‘egrek’ (a sickle-like) tool is the only applicable way to harvest FFB taller than 3 m.

The upper body segments such as neck, shoulder, back and arms were ergonomically vulnerable in most cases of the harvesting tasks. The results of RULA revealed that the work postures are outside safe ranges and further investigation and changes are required immediately. Finally, the results of work motion simulations could formulate tasking procedures that may minimize awkward posture and MSD risk.

Keywords: anthropometry, motion, posture, harvesting task, oil-palm

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1 Introduction

Oil Palm (Elaeis guineensis Jacq.) is the most potential oil producer plant which can be cultivated in most area and most type of soil in Indonesia, and presently are concentrated mostly in the Islands of Sumatra and Kalimantan, and small parts in Sulawesi. Oil-palm plantations are highly profitable if well managed. Once the plants are planted, they will start to produce fruits since the third or fourth year of planting and continuously productive for twenty years old, or even more. As the largest palm-oil producer in the world that covers more than 8 million ha planting areas and 20 Mt CPO (crude palm oil) production annually (Statistic Indonesia, 2013), palm-oil industry grows increasingly and it is very important contributor to export commodity and employment in Indonesia.

Manual handling and human power are being very important and dominant role in conducting farming activities in Indonesia (Komatsuzaki and Syuaib, 2012), not exceptionally in oil-palm plantations. Various types of tools, equipment and simple machines have been commonly used to accomplish a variety of agricultural works, and new types of machines or new working techniques and procedures are also sometimes introduced to improve the productivity of agricultural operations. In this regard, applications of ergonomics are required in the

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work system design to attain a good match and suitability between worker characteristics and task demands. Ergonomics is concerned to ensure safety, enhance efficiency and comfort ability and eventually to leverage productivity of the work system.

Anthropometry is a branch of Ergonomics that considers the measurement and description of the dimensions of the human body and it implication to the work system design, while motion study concerns with developing a better method of doing the work. So, considerations of anthropometry, posture and motion analysis in the design of work system will improve the system performance and efficiency along with safety and comfort, as well as to prevent occupational accidents or injuries. However, the application of ergonomic to the design of agricultural tools, equipment and work system has not been implemented in practice in Indonesia due to the lack of a proper database.

The main objective of this study is to obtain anthropometric data of agro-industrial workers, which especially focussing on Oil-palm plantation in Sumatera, Kalimantan and Sulawesi islands as the concentrated location of the plantations areas. Furthermore, analysis of work-motions and postures were also conducted in aiming to know the postural load and risks associated with the oil-palm harvesting tasks and the appropriate intervention needed to minimize the risks. Survey and data collection were carried out in three diverse plantation regions to find out the body-dimensional characteristics of the harvesting workers as well as the harvesting work-motion in various work systems and conditions accordingly.

2 Harvestingworks of oil-palm plantation in Indonesia

Harvesting is the most important but considered to be strenuous and crucial work in the oil-palm industries. Good harvesting technique and timing are necessary to result in good productivity.Despite the use of machinery, the achievement of the industries is constrained by the harvesting method which is conventional and labour intensive. The harvesting mostly done manually by human powerwhich is quite arduous and difficult, as well as risky in term of work safety and musculoskeletal disorders (MSD). The fresh fruit bunches (FFB) which lay between the stalks of the leaves at the top of the canopy of trees harvested with a tool shaped like a “chisel” or “sickle” that is mounted to a long telescopic steel pole.

According to the cutting techniques and tool used in connection with the stage of the tree’s growth and tallness, the tasks can be divided into two typical harvesting techniques. The first is the “push-cutting” technique using a chisel like tool (locally named as “*dodos*”) which is typicallyapplied foryoung palm tree less than 3 m high (Figure 1). And the second is the “pull-cutting” technique using a sickle like tool (locally named as “*egrek*”) which is applied for the palm trees taller than 3 m (Figure 2).

(a) FFB <stature height, (b) FFB =stature height, (c)FFB >stature height, (d)the tool& position

Figure 1 Harvesting in a ‘short’ palm tree (≤ 3 m height) by ‘push-cutting’ technique

(a) FFB < 6 m tallness, (b) FFB > 6 m tallness, (c) the tool& position

Figure 2 Harvesting in a 'tall' palm tree (more than 3 m height) by 'pull-cutting' technique

When a palm tree is in the early stage of harvesting, the height of the FFB is about the same or less than the stature of the worker, thus to harvest it is relatively easy and simple. However, when the palm tree grown to be taller and taller again, the harvesting tasks become not easy anymore; it is quite risky and hard in which requires a good technique, skill and strength. The targeted FFB could be located at the canopy of the tree as high as 20 m above the ground, and the weight of the FFB could be more than 30 kg. Appropriate design of tools and tasks is very important to ease the harvesting operations and reduce occupational risks; and therefore, considerations of ergonomic principles and approaches are essential.

3 Methods

3.1Anthropometric measurement and analysis

Anthropometric surveys were undertaken in three different locations of oil-palm plantationsin Sumatera (represent western-region of Indonesia), Kalimantan (middle-region of Indonesia) and Sulawesi (the eastern region of Indonesia).Totally 141 subjects were randomly selected among the workers on the plantations, all are professional harvesting workers, males and in good health and physical condition. The procedures of anthropometric data collection were explained to the subjects before the measurement started to get cooperation from them and so the accuracy of the measurement can be maintained.

A portable weighing scale with an accuracy of 0.1 kg measured the body weight, and a commercial Anthropometer set and a measurement tape with accuracy of 1 mm measured the other forty-one anthropometric dimensions of the subjects. Thirteen measurements were performed with the subjects in the standing position, and the other twenty-nine measurements were performed with the subjects in the sitting position. Subsequently, the index of RSH (relative sitting height) was calculated, and the ages of the subjects were likewise recorded. The measurement techniques and terminologies referred to the guidelines in Anthropometric Source Book (NASA, 1978; Kroemer and Grandjean, 1997; Pheasant, 2003).

A computer recorded the collected data, and a common spreadsheet software package was used to analyse them. The data set for each dimension in the sample's groups were checked to ensure that they represent a normal distribution. The values of the mean, standard deviation (SD), standard error of the mean (SEM) and coefficient of variation (CV) were calculated. The 5th, 50th and 95th percentile values were calculated accordingly. The ANOVA F-test was used to compare the significant differences among the data groups within the three distinct diverse regions.Significant difference between the means of measured dimensions was indeed accepted if a significant outcome exists ($p < 0.05$).

3.2 Work motion and posture analysis

Work-motions analyses were undertaken based on video record of the actual harvesting tasks collected from 23 workers in the plantation fields. The subjects were explained to do harvesting task as naturally as they use to do, and each of them was observed for 8 repetitions work-cycles of FFB harvesting. The tasks' motions and postures of each recorded work-cycles were captured and analysed. The ranges of motion (ROM) of related body segments were then identified and typical patterns of the work-motion could be summarized. In addition, body-map questionnaire was also collected from the workers to find out subjective perception regarding the musculoskeletal discomfort or fatigue in conducting the harvesting tasks. Finally, rating of musculoskeletal loads and risks were analysed with Rapid Upper Limb Assessment (RULA).

RULA was introduced by McAtamny and Corlett (1993) which provides an easily calculated rating of awkward posture and musculoskeletal loads in such a task where worker has risk of neck and upper-limb postures and burden. The tool provides a single score as a 'snapshot' of the task, which is a rating of the posture, force and movement required. RULA consists two groups of posture analysis, i.e.: 'Group A' for arm &wrist analysis, and 'Group B' for neck, trunk &leg analysis. By adding force load and muscle use factors, then the total score of the posture analysis can be calculated, as it is guided in the RULA procedure (Figure 3).The risks are calculated into a score of 1 (low) to 7 (high), which then grouped into four action levels of risk control.

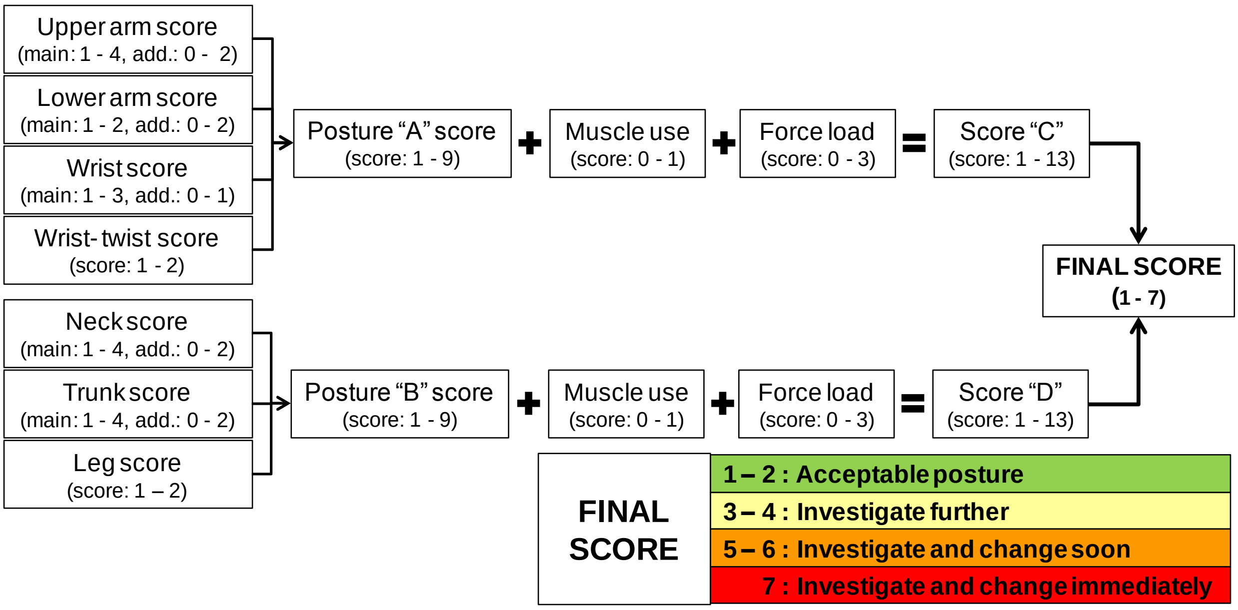


Figure 3 The RULA assessment procedure (adapted from: McAtamney and Corlett, 1993)

4 Results and discussion

4.1 Anthropometricmeasures and their comparison across regions

A set of forty-two anthropometric measurements had been taken and the values of SD, SEM, CV, and the 5th, 50th and 95th percentiles of each of the measures were calculated. Table 1 presents the results of the data analyses and how they are distributed with respect to the three distinc regions of study. As for comparison, anthropometry of Javanese farm workers which have been reported previously by the Author (Syuaib, 2015) are also presented. Generally, the SEM values of the data groups are lower than 1.0, but the values associated with body weight, arm span and vertical reaches are in the range of 1.1 to 1.5.These SEM values are accepted to the 95% confidence limit therefore indicated that the samples are representative of the targeted population.

Table 1 The results of anthropometric measurements

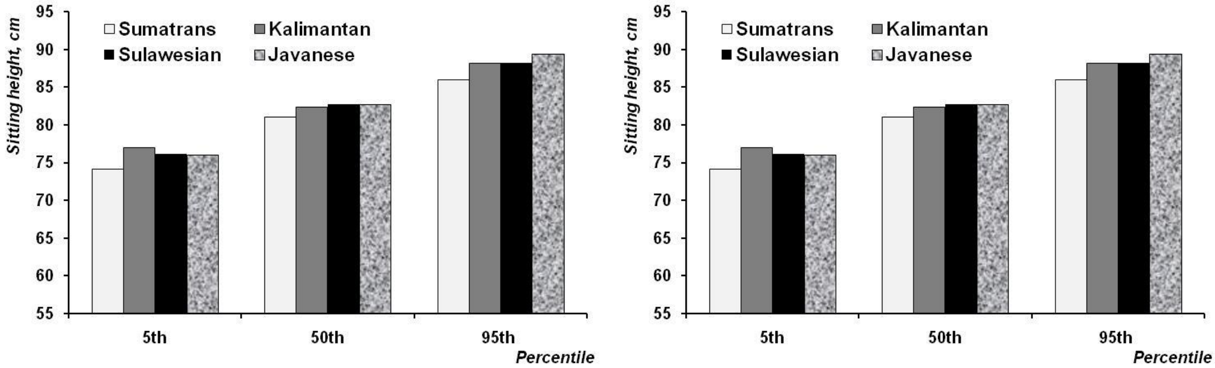
NO	ANTHROPOMETRIC MEASURE	SUMATERA						KALIMANTAN						SULAWESI						JAVA*					
		Percentiles			SD	SEM	CV (%)	Percentiles			SD	SEM	CV (%)	Percentiles			SD	SEM	CV (%)	Percentiles			SD	SEM	CV (%)
		5th	50th	95th				5th	50th	95th				5th	50th	95th				5th	50th	95th			
1	Stature	150.7	160.0	168.7	6.0	0.9	3.7	151.1	160.0	169.8	6.3	1.0	4.0	147.7	160.2	169.6	7.4	1.0	4.6	153.0	162.0	171.0	5.5	0.4	3.4
2	Eye height	138.1	150.0	158.3	7.1	1.0	4.7	139.3	148.0	160.3	6.4	1.0	4.3	137.1	149.0	159.9	7.7	1.1	5.2	141.7	151.2	160.6	5.7	0.4	3.8
3	Shoulder (Acromial) height	123.4	134.3	141.0	5.5	0.8	4.1	123.1	133.0	141.7	5.8	0.9	4.3	123.0	133.3	140.7	6.4	0.9	4.8	127.0	135.8	144.6	5.3	0.4	3.9
4	Elbow height	92.2	101.1	109.0	5.3	0.8	5.2	93.2	101.6	108.1	6.0	0.9	6.0	88.9	96.9	106.3	5.4	0.8	5.6	93.9	101.2	108.5	4.4	0.3	4.4
5	Waist height	87.5	96.8	101.7	5.8	0.8	5.9	86.4	95.6	99.9	4.1	0.6	4.3	82.1	89.3	97.6	5.7	0.8	6.4	87.9	95.0	102.0	4.3	0.3	4.5
6	Knuckle height	62.4	71.0	76.0	4.2	0.6	5.9	63.5	70.0	75.7	4.0	0.6	5.7	57.3	65.2	70.8	6.5	0.9	10.0	64.1	70.2	76.4	3.7	0.3	5.3
7	Fingertip height	53.0	58.2	62.7	4.4	0.6	7.6	52.5	57.9	64.8	4.0	0.6	6.9	50.2	56.9	62.4	5.3	0.8	9.4	53.8	59.8	65.7	3.6	0.3	6.1
8	Vertical fingertip reach	189.7	201.8	212.0	8.1	1.2	4.0	188.3	202.4	214.7	9.3	1.4	4.6	185.3	201.9	218.1	10.8	1.5	5.4	nda	nda	nda	nda	nda	nda
9	Vertical grip reach	176.1	190.0	201.3	8.5	1.2	4.5	178.1	191.5	203.7	8.4	1.3	4.4	179.0	195.5	210.7	10.3	1.5	5.3	181.5	195.1	208.6	8.2	0.6	4.2
10	Forward fingertip reach	70.7	78.0	84.0	4.4	0.6	5.7	75.4	81.0	86.3	3.8	0.6	4.7	64.6	69.8	76.0	3.9	0.6	5.6	73.9	81.3	88.8	4.5	0.3	5.6
11	Forward grip Reach	58.0	66.0	70.7	4.0	0.6	6.1	64.1	70.0	75.5	4.7	0.7	6.7	56.5	62.0	68.9	3.9	0.6	6.5	62.8	69.9	77.1	4.3	0.3	6.2
12	Arm span (fingertip)	153.7	168.8	181.3	8.9	1.3	5.3	155.3	167.9	177.9	7.1	1.1	4.2	152.8	166.1	176.6	8.3	1.2	5.0	156.1	168.9	181.6	7.8	0.6	4.6
13	Elbow span	72.0	84.0	95.0	7.2	1.0	8.6	79.1	85.5	90.3	3.8	0.6	4.5	73.4	84.6	91.8	6.5	0.9	7.7	78.1	85.9	93.8	4.8	0.3	5.6
14	Head length	16.1	18.0	21.0	1.5	0.2	8.1	16.8	18.0	19.3	0.8	0.1	4.5	17.0	18.2	19.2	0.7	0.1	3.7	nda	nda	nda	nda	nda	nda
15	Head breadth	15.2	17.0	19.5	1.4	0.2	8.2	14.8	15.8	16.8	0.6	0.1	4.0	14.6	15.2	16.3	0.6	0.1	3.9	nda	nda	nda	nda	nda	nda
16	Hand length	17.0	18.3	20.0	1.0	0.1	5.5	16.4	18.0	19.6	1.1	0.2	5.9	16.2	18.0	19.8	1.2	0.2	6.5	16.8	18.3	19.7	0.9	0.1	4.9
17	Hand breadth	7.8	8.4	9.7	0.7	0.1	8.7	7.4	8.6	9.8	0.6	0.1	7.0	7.6	8.8	9.5	0.6	0.1	6.5	7.2	8.3	9.5	0.7	0.1	8.6
18	Fist circumference	23.0	25.5	27.6	1.6	0.2	6.4	25.0	27.5	30.0	1.5	0.2	5.4	25.3	27.4	29.1	1.3	0.2	4.6	nda	nda	nda	nda	nda	nda
19	Grip diameter (inside)	3.6	4.3	5.0	0.4	0.1	10.3	4.6	5.2	5.7	0.4	0.1	7.4	4.2	4.9	5.6	0.5	0.1	10.3	3.6	4.3	5.0	0.4	0.0	9.9
20	Maximum hand-spread length	19.7	21.2	23.0	1.6	0.2	7.4	19.2	21.0	23.1	1.5	0.2	7.0	18.7	20.8	23.0	1.7	0.2	8.1	nda	nda	nda	nda	nda	nda
21	Tumb length	6.0	6.1	7.0	0.5	0.1	8.3	5.5	6.1	6.9	0.5	0.1	7.5	5.6	6.3	7.3	0.5	0.1	8.0	nda	nda	nda	nda	nda	nda
22	Sitting height	74.2	81.0	86.0	3.6	0.5	4.5	77.0	82.3	88.2	3.9	0.6	4.7	76.1	82.7	88.2	3.9	0.5	4.7	76.0	82.7	89.5	4.1	0.3	5.0
23	Sitting eye height	64.4	70.8	77.0	3.7	0.5	5.3	64.9	71.6	75.5	3.8	0.6	5.3	64.0	71.4	77.1	4.0	0.6	5.6	64.1	71.4	78.8	4.5	0.3	6.2
24	Sitting shoulder (Acromial) height	53.0	57.0	60.0	2.6	0.4	4.5	49.6	55.5	60.8	3.2	0.5	5.8	50.3	56.4	62.3	4.8	0.7	8.4	50.9	56.4	61.9	3.4	0.2	6.0
25	Sitting elbow height	17.9	21.0	27.3	3.1	0.4	14.5	17.0	21.2	26.3	3.2	0.5	15.0	15.5	21.3	24.7	3.1	0.4	14.5	16.5	21.8	27.2	3.2	0.2	14.9
26	Knee height	45.7	50.3	54.3	2.9	0.4	5.8	45.4	49.6	52.8	2.4	0.4	4.8	42.5	46.6	51.2	2.6	0.4	5.6	46.8	52.1	57.4	3.2	0.2	6.2
27	Popliteal height	34.9	41.3	47.7	3.6	0.5	8.8	36.9	41.6	43.9	2.3	0.3	5.4	36.7	39.3	43.0	2.5	0.4	6.4	nda	nda	nda	nda	nda	nda
28	Sit-Vertical fingertip reach	116.0	124.0	132.0	5.3	0.8	4.2	113.1	125.2	132.5	6.5	1.0	5.2	116.3	128.4	138.8	7.6	1.1	5.9	nda	nda	nda	nda	nda	nda
29	Sit-Vertical grip reach	105.0	112.5	119.3	4.7	0.7	4.2	103.1	113.5	120.3	5.9	0.9	5.2	109.1	120.6	127.5	6.5	0.9	5.4	nda	nda	nda	nda	nda	nda
30	Arm length (downward fingertip)	69.0	74.0	79.0	3.2	0.5	4.4	67.3	74.0	78.3	4.2	0.6	5.6	66.4	72.1	78.8	4.1	0.6	5.7	nda	nda	nda	nda	nda	nda
31	Downward grip reach	56.0	61.0	64.0	3.2	0.5	5.2	57.1	63.0	66.2	3.2	0.5	5.0	58.8	64.8	70.4	3.9	0.5	6.0	nda	nda	nda	nda	nda	nda
32	Upper-arm (shoulder-elbow) length	28.0	30.0	33.8	2.2	0.3	7.4	30.5	33.6	36.1	2.3	0.4	6.8	23.8	29.7	32.9	2.8	0.4	9.4	29.1	31.8	34.5	1.6	0.1	5.2
33	Forearm hand (elbow-fingertip) length	39.0	44.0	47.8	2.6	0.4	5.9	41.5	45.4	49.5	2.4	0.4	5.2	39.3	42.6	46.9	2.4	0.3	5.5	42.1	45.6	49.0	2.1	0.2	4.5
34	Forearm grip (elbow-grip) length	29.0	32.0	42.3	3.7	0.5	11.7	31.1	34.0	37.0	1.9	0.3	5.6	32.4	35.6	39.3	2.2	0.3	6.3	nda	nda	nda	nda	nda	nda
35	Buttock-knee length	50.0	55.0	58.8	3.1	0.4	5.7	50.0	53.3	56.9	2.3	0.4	4.3	47.4	51.9	56.0	3.0	0.4	5.7	49.5	55.3	61.2	3.6	0.3	6.4
36	Buttock popliteal length	40.0	46.0	50.0	3.1	0.4	6.8	40.1	42.8	47.6	2.5	0.4	5.9	37.3	42.2	46.6	2.9	0.4	6.9	40.6	46.8	52.9	3.7	0.3	7.9
37	Shoulder breadth (bideltoid)	42.0	45.0	50.0	4.6	0.7	10.2	39.2	41.9	45.4	2.1	0.3	4.9	38.1	41.6	44.1	2.0	0.3	4.8	36.4	41.9	47.4	3.3	0.2	7.9
38	Hip breadth	27.0	30.0	35.5	2.9	0.4	9.7	29.0	32.8	36.5	2.2	0.3	6.8	29.3	32.4	35.7	2.1	0.3	6.3	25.3	30.1	34.8	2.9	0.2	9.6
39	Cest (bust) depth	17.6	21.0	25.0	2.2	0.3	10.6	18.1	20.8	22.3	1.5	0.2	7.4	17.1	19.7	22.6	1.6	0.2	8.0	15.7	20.0	24.3	2.6	0.2	13.0
40	Foot length	22.5	25.0	26.5	1.2	0.2	4.8	22.0	24.3	26.5	1.5	0.2	6.3	21.5	23.9	26.5	1.5	0.2	6.3	22.1	24.2	26.2	1.3	0.1	5.3
41	Foot breadth	9.6	10.5	12.0	0.7	0.1	7.1	9.8	10.7	11.5	0.6	0.1	5.6	8.8	10.1	11.2	0.8	0.1	7.6	9.0	10.1	11.2	0.7	0.0	6.8
42	Body weight (kg)	46.0	54.5	74.0	8.2	1.2	15.1	48.0	55.0	70.6	7.9	1.2	14.4	43.9	55.0	64.1	7.7	1.1	14.0	40.6	57.1	73.5	10.0	0.7	17.5

*) Refer to: Syuaib, MF. 2015. Applied Ergonomics

Regarding the coefficient of variation, the values of CV >10% are associated with body weight, sitting elbow height and grip diameter, and the values of CV < 10% are generally associated with the remaining body dimensions in the data groups. According to Pheasant (2003), the common characteristic ranges of CV (%) of the various anthropometric dimensions are: 3-4 for stature, 3-5 for body height related dimensions, 4-5 for parts of limbs, 5-9 for body breadths, 6-9 for body depths, 4-11 for dynamic reach and 10-21 for body weight. Thus, most of the collected data are in the ranges of suggested CV.

It is generally understood that the variation in the body dimensions of people are reflected in their race or ethnical backgrounds and geographical locations, with some of these variations being significantly different (Pheasant, 2003; Bridger, 2003; Lin and Wang, 2004; Prado-Lu, 2007; Dewangan et al., 2008; Agrawal et al., 2010;Is'eri and Arslan, 2009; Karmegam et al., 2011; Sadeghi et al., 2015; Syuaib, 2015).Statistical analysis (ANOVA) revealed significant differences in most of mean body dimensions among people in the regions of study.Total comparisons of 28 dimensions have significant outcomes among the data groups (25 items within $p < 0.01$ and the other 3 items within $p < 0.05$). However, no significant difference was found between the mean of the other 14 dimensions, including body weight, stature, eye height, shoulder height, arm span and sitting heights. In addition, all of the breadths and depth dimensions were found to be significantly different ($p < 0.01$). These results suggest that consideration of ethnic diversity is require in designing tools and machinery which ergonomically suitable to the users.

In comparing the dimensions of stature and sitting height among the people groups, the mean stature and sitting height of Sumatrans were found as among the shortest while Javanese were the tallest one (Figure 4). The mean stature of the Sumatrans, Kalimantan's and Sulawesi's are in the range of 160.0 – 160.2 cm, and they are slightly shorter than their Javanese counterpartwhich is 162.0 cm. While the mean sitting height of Sumatrans is 81.0 cm which is slightly shorter than that of the other people groups (82.3 – 82.7 cm).



(a) stature height ***(b) sitting height***

Figure 4 Comparison of stature and sitting height among people in the regions

Regarding the mean value of the relative sitting height (RSH), ANOVA found a significant different (F=6.28, p<0.01) among the values of the data groups. An interesting result was found where comparing the RSH among different percentile values (Figure 5), there is a tendency that the shorter the sample size, the lower the RSH value observed. The RSH of each data group was in the range of 0.47-0.49, 0.51-0, and 0.54-0.55 for the 5^{th}, 50^{th} and 95^{th}percentiles, respectively. Referring to Pheasant (2003), the shorter samples (5th percentiles) in all regions are categorized as "long-legged" (RSH < 0.50) and the taller ones (95th percentiles) are categorized as "short-legged" (0.53 < RSH < 0.55), and the average of the groups (50th percentiles) are categorized as between short and long-legged (0.50 < RSH < 0.53). In other words, the RSH tends to be lower for the short samples compared to the tall samples. These results reveal that the trunk of the Indonesian contributes more to the difference in the stature dimension compared to the lower limbs; generally, it is similar proportions to the Far-Eastern people, but different to Europeans and Middle-Eastern people (Pheasant, 2003).

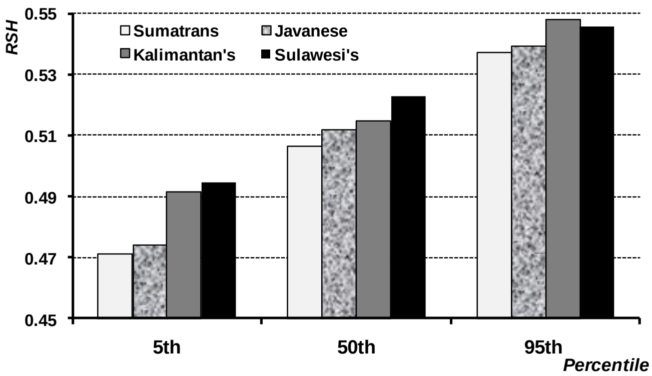


Figure 5 Comparison of the RSH among people and percentile values in the regions

It was also an interesting finding when comparing the tendency of the RSH with concern to the "east - west" geographical regions of the study areas. Geographically, Sumatera is located on the most western side among the other regions of this study, and then followed to the eastward by Java, Kalimantan, and finally Sulawesi is located on the most eastern side among the other regions. As it is illustrated in Figure 5, generally the RSH tend to be lower for the samples group in the eastern region compared to that ones in the western ones. Thus, this result indicated that the people group from the western region of Indonesia tends to have lower RSH compared to their counterpart from the eastern region.

Anthropometric data are a prerequisite for designing agricultural tools and equipment that enable workers to achieve better performance and productivity while providing better safety and comfort. The differences in anthropometric characteristics among people and population groups emphasize the usefulness of this study in the context of designing agricultural tools, equipment, machinery and their operational procedures. Author has previously reported the results of anthropometric study of Indonesian farm workers in Java Island (Syuaib, 2015); hence, the results of this study may beneficial to enrich the database for more diverse population and types of agricultural operations in Indonesia. The measures of stature, shoulder height, waist height, knuckle height, knee height and arm length are important for designing manual handling tasks; arm and hand related measures are important for designing handle and hand-tools. The measures of sitting-related heights, buttock-knee and popliteal lengths, shoulder and hip breadths, elbow height and grip reach are important for cabin design of agro-machinery or vehicles; elbow and knee heights are important for seat and table designs, and eye height is important parameter in designing visual display & control of machinery.

4.2 Questionary survey of the harvesting work burden

Questionnaires have been collected from 141 harvesting workers in the areas of study to find out the subjective perceptions regarding body-part burden, fatigue, pain or discomfort in conducting the harvesting tasks. The prevalence of musculoskeletal fatigue or discomfort was significant in trunk and upper extremity, particularly on waist and shoulder.As it is presented in Figure 6, nearly 29 %, 28%, 10% and 5% of the respondents experienced discomfort and fatigue mostly on theirwaist, shoulder, back and neck, respectively; whereas 14% of the workers experienced discomfort and fatigue mostlyon their upper limbs or lower limbs. These results indicated that the upper body parts were mainly implicated and loadedin conducting the FFB harvesting tasks. However, the degree and causative factors of pain or discomfort experienced by each worker were varied and vague.Therefore, motion analysis was conducted for further investigation on the harvesting tasks.

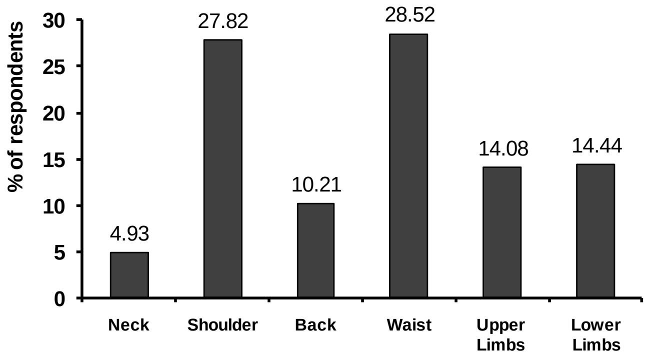


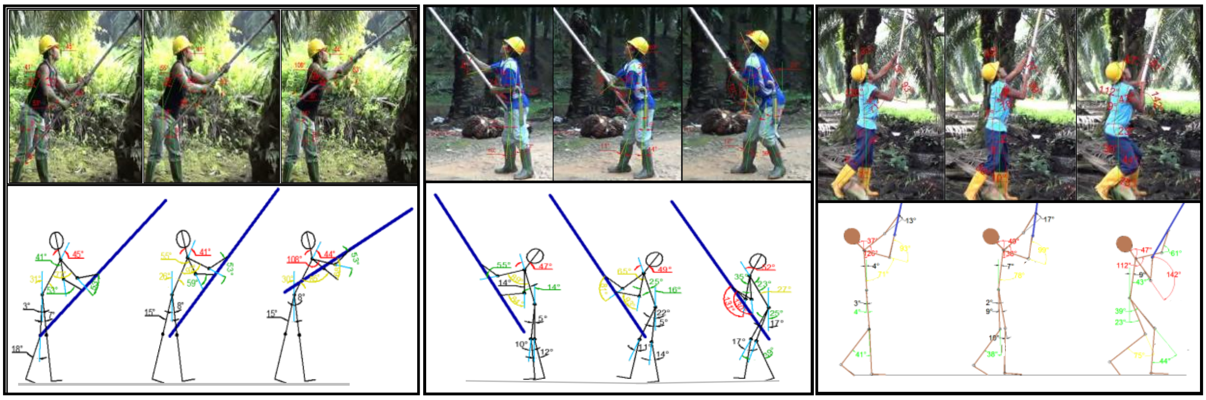
Figure 6 Distribution of subjective perception of the workers regarding the most burdened body parts in conducting palm harvesting tasks

4.3 Work motion analysis on the FFB harvesting tasks

Harvesting of FFB is not an easy job, but it requires heavy strength, proper skill and technique. Concerning the nature of the harvesting work-motion, the positions of the trunk, upper limbs, and lower limbs are being awkward and intently muscle use and force load are needed. To observe the characteristics of the work-motions, video recording were made upon the actual harvesting operations in the fields that were involving diverse tool use and working techniques associated to the different high of FFB targeted and field condition. Sequential motions of the harvesting work cycle with focusing on the FFB cutting tasks were captured and analysed so that they can be properly assessed in the laboratory.

When a palm tree is in the early stage of harvesting, the height of the FFB is about the same or less than the stature of the worker, thus the harvesting tasks is relatively easier where the neck and trunk of the harvester are relatively in normal position or sometimes just slightly flexions are needed. On the other hand, when a palm tree has grown to a certain height which is higher than the stature of the worker, the harvester needs to tilt his head to observe and identify the targeted FFB, while in the same time he has to lift and balance the cutting tool to the appropriate height and position of the targeted FFB; so the neck, trunk and shoulder and upper limbs have to be extended consequently. The higher the FFB position the greater the degree of extension needed. Moreover, a combination of adverse posture, extreme ranges of motion in most of body parts and repetitive muscle use and prolonged load are required to harvest FFB on a high tree, particularly on the 6 m FFB height or more.

Generally, the neck and trunk were observed to be extended, flexed and sometimes slightly rotated; while the upper limbs were forcefully pushing or pulling and sometimes swinging the tool's pole to cut the targeted FFB. The degree of the body-parts' motions vary according to several factors, mainly are the anthropometry of the harvester, the height of the targeted FFB and the type of cutting technique (push or pull).Based on these characteristics, author divided the motion analysis in three typical harvesting tasks, such as: (1) push-cutting with a *dodos* tool that applied on less than 3 m FFB height (D), (2) pull-cutting with an *egrek* tool that applied on 3-6 m FFB height (E1), and (3) pull-cutting with *egrek* tool that applied on more than 6 m FFB height (E2).Figure 7illustrates the typical patterns and the mannequin modelling of the work motions.



(a)the D task (< 3 m FFB height), (b) the E1 task (3 - 6 m FFB height), (c) the E2 task (> 6 m FFB height)

Figure 7 Three sequential captures of work-motion patterns of the harvesting tasks (the existing procedures in the fields, no intervention)

The 'push-cutting' tasks were conducted by using a *dodos* tool attached to a steel-pole with a length of 2 m. The height of the targeted FFB may range between 1 ~ 3 m above the ground (see Figure 1 and Figure 7.a.).The push-cutting technique requires a technical skill to 'pin-point' the cutting target, while exerting muscular force to drive the tool and to cut the FFB targeted as well as to keep the body posture in balance. The motion analysis revealed that to cut a shorter target (less than stature height of the operator) required more flexions on back, hip/waist, knees and ankles; but less neck extension, shoulder flexion and trunk bending. In another hand, to cut a higher target (2 ~ 3 m height) required extreme extension on neck, and shoulder and elbow flexions; sometimes upper arm abduction, trunk side-bending, and wrist deviation were necessary. The neck extension and shoulders flexions were found as critical posture in most cases of the cutting tasks. Neck extension (NE) 25°+ and shoulder rise mostly required when the cutting target located on more than 2 m high. However, the ROM of the other body parts were varied in certain level depend on some factors, such as: the height of the FFB targeted, length of the tool, body dimensions of the operator and the work custom of the operator (i.e.: forward or sideward stroke, working distance from the tree, right or left handed). As for muscular use and load, two-handed arms force was mainly applied in which motions of the shoulders (from extension to flexion) and arm were needed, abduction in one shoulder and adduction in another shoulder, wrist bending sometimes was required. Two or three repetitive strikes were sometimes requisite to cut the FFB, especially when it is relatively bigger in size and higher in position.

The 'pull-cutting' tasks were conducted by using an *egrek* tool attached to a long steel-pole (see again Figure 2, Figure 7.b and Figure 7.c.). The steel pole is designed as a telescopic assembly of some 3 m long poles, so pole's length could be adjusted according to the height of the cutting target. Compared to the push-cutting, the pull-cutting technique seems to be much more difficult and harder work. It requires more muscular force and technical skill to stand and drive a long steel-pole and then to 'shove in' the sickle tool to the targeted FFB's stalk which is hidden in a narrow space among the base of the palm leaves. Therefore, extensions of the neck and back, and flexions of the shoulder and elbow were observed always in extreme position in all cases of this typical task; and the range of extension was linearly increased in accordance to the height of the cutting target. Shoulder raise and trunk bending were mostly required. As for muscular use and load, two-handed arms force was mainly applied in which shoulders and elbow flexions are mainly important to pull the tool powerfully to cut the target, wrist bent and twist sometimes also needed to keep the tool position in line with the arm motion. Two or three repetitive pulls were mostly needed to cut the FFB. Extreme neck extension (NE 30 °+) was mostly observed when the workers conduct this particular task to keep their visual control to the cutting point. In addition, bending of trunk and flexions of knees and ankles sometimes naturally occurred to exert additional power while at the same time to maintain the balance of body posture, especially when the worker cuts a relatively big size FFB located at difficult position.

ROM analysis observed that the upper body segments (neck, shoulder, back and arms) mostly are in extreme positions and potentially affected by MSD. The higher the tree (FFB targeted) and the shorter the worker, the greater the range of motion (flexions or extensions) observed. To ensure that all possible risks are concerned, the maximum range of motions those take part in the actual tasks was observed and identified, and the results are summarized as in Table 2. Generally, theshorter workers have a comparatively higher risk than that of the taller ones in conducting harvesting tasks on the same FFB height, particularly for the FFB height of more than 3 m.

Table 2 The results of ROM analysis of the existing harvesting tasks

Body Part	Motion	Summary of the ROM*) observed in the typical harvesting tasks		
		The D tasks	The E1 tasks	The E2 tasks
Neck	Extension (NE)	0 - 30 º	31 º+	31 º+
Shoulder	Flexion (SF)	50 - 144 º	51 - 148 º	76 - 161 º
	Extension (SE)	6 - 58 º	0 - 45 º	0 - 55 º
Back	Flexion (BF)	10 - 24 º	12 - 33 º	19 - 40 º
	Extension (BE)	0 - 18 º	5 - 20 º+	6 - 20 º+
Elbow	Flexion (EF)	78 - 120 º	112 - 144 º	110– 150 º+
Hip	Flexion (HF)	17 - 48	8 - 44 º	17 - 55 º
Knee	Flexion (KF)	30 - 60 º	29 - 77 º	35 - 81 º
Ankle	Flexion (AF)	8-17 º	10 - 19 º	8 - 24 º

Note: **) the maximum range of motion observed within a cutting cycle, both right and left body parts were concerned, summarized fromall collected data from allrecorded subjects*

Considering the natural ROM suggested by Kroemer and Grandjean (1997) and the four zones of ROM referred to Opensaw and Taylor (2006), the 30 ° NE, 90 ° SF, 31 ° SE, 45 ° BF, 20 ° BE, 120 ° EF, 90 ° HF, 90 ° KF and 20 ° AF were predetermined as the extreme limits of the body motions accordingly. Thus, motion analysis indicated that the neck (NE), shoulder (SF and SE), back (BF and BE) and elbow (EF) were frequently at the extreme limit of motion range. In another words, these results revealed that the upper segments of the body of the workers were mostly in an extremely awkward position and potentially to be affected by MSD risk when conducting the existing techniques of the harvesting tasks. Therefore, RULA (Rapid Upper Limb Assessment) was conducted for further investigation to reveal the rating of awkward posture and musculoskeletal load and risks in various conditions of the harvesting tasks.

4.4 Analysis of RULA on the FFB harvesting tasks

RULA investigated the activities associated with awkward posture in the harvesting tasks and the final scores indicate the level of postural load and intervention required to reduce MSD risks. Generally, the results revealed that the working postures in the harvesting tasks were extremely discomfort because the Final Scores 7 was resulted in most of cases of the harvesting tasks. This means that the workers were working in the worst posture with an immediate risk of injury from their work posture.

As to compare the awkward posture of the harvesting tasks in different working conditions and techniques, Author divided the "D" tasks in two categories as "D1" *dodos* technique on FFB height ≤ 2 m and "D2" for *dodos* techniqueon FFB height 2-3 m, and the "E" tasks in 3 categories as "E1" for *egrek* technique on FFB height 3-6 m,"E2" for *egrek* technique on FFB height 6-12 m and "E3" for *egrek* technique on FFB height > 12 m. As for the final results, Figure 8 shows the Final Scores of RULA with respect to the different working condition and techniques accordingly. The scores on the D1 task seem to be the 'border line' of extreme work posture, because the Group A, Group B and the Final scores were 7. While the scores on the higher cutting targets (D2, E1, E2 and E3) were 7+. Moreover, special attention is obviously important for the tasks on the FFB height more than 6 m (E2 or E3) because the posture scores were undoubtedly awkward whereas the Group A and B scores were in the range of 11 – 13 (within the maximum score possible in RULA is 13). Finally, the scores of RULA set the FFB harvesting tasks generally in the Action Level 4, which means that the working postures are outside safe ranges, repetitive motion of muscle use and force load are required. Therefore, further ergonomics investigation and intervention are needed immediately due to develop better design of working procedures and tools dimension which is as practicable to prevent various risk factors and injury, and eventually to minimize the MSD risks.

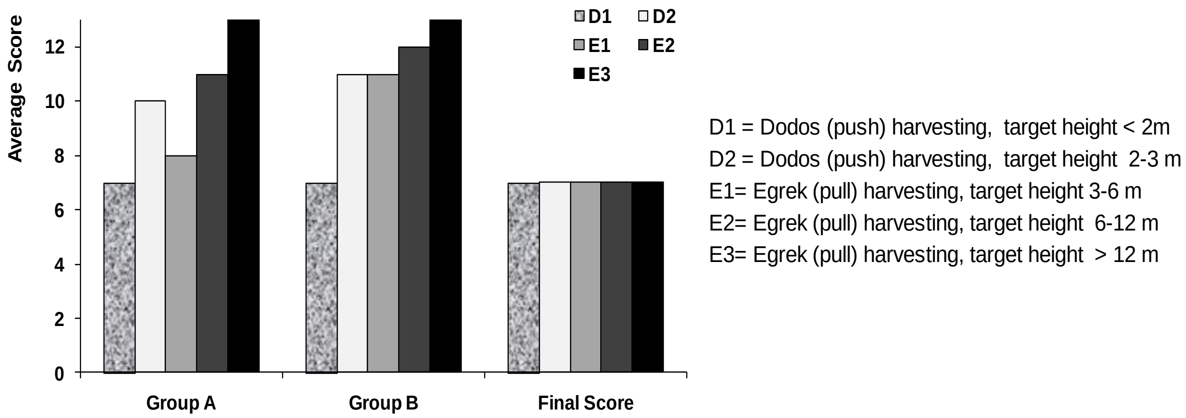
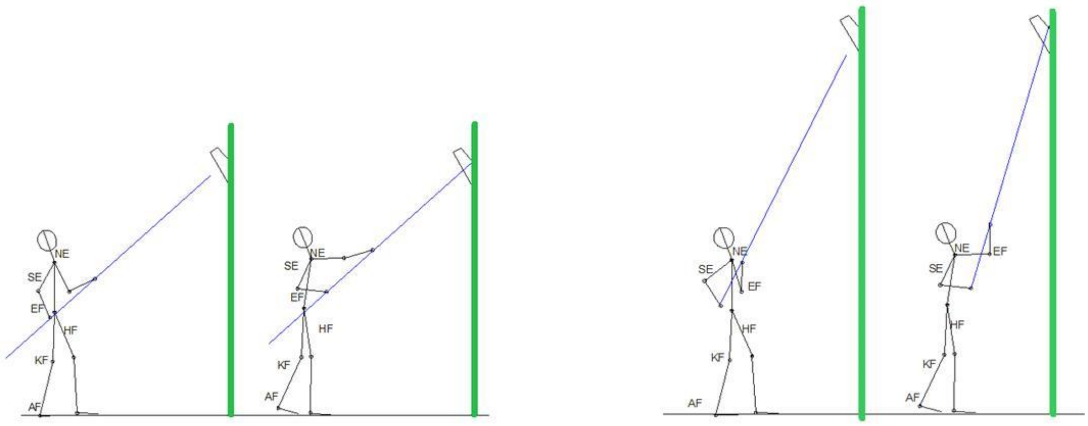


Figure 8 Comparison of the RULA (Group A, Group B and Total) scores of the harvesting tasks in different work condition

4.5 Working design to prevent awkward postures on the FFB harvesting tasks

The "push cutting technique" is applicable to cut FFB on the palm tree with a height less than 3 m by using a *dodos* tool attached to a steel-pole length of 2 m. The awkwardness of arms, legs and trunk postures varied depending on the height position of FFB targeted. The average score of Posture A was 4 and 7 for high FFB < 2 m (D1) and > 2m (D2), respectively; while the average score of Posture B was4 and 8, accordingly. Furthermore, the score of muscle use was 1 (repeatedly action) and force load was 3 (about 5-10 kg equivalent) for all cases. Thus, the Total Score of Group A became 7 and 10, while the Total Score of Group B was 4 and 8, respectively for the D1 and D2; and finally, the Final Score 7 has resulted in all cases. As for comparing the tasks with different target height, Figure 9 shows a schematic representation of workers posture when performing the D1 and D2 tasks. Upper arm flexion 90+, shoulder raise, lower arm abduction/adduction and wrist extension were mostly required in the D2 task. Neck extension (sometimes excessively) was needed as well. The shorter the worker and the higher the tree, the greater the range of motions was observed. Consequently, the postures of the neck, shoulder and arm were not comfortable. It is necessary to change the tasking procedure with emphasizing the acceptable range of flexions of the neck, shoulder and arm. Thus, harvesting technique with appropriate working distance and length of the pole that suited to the workers anthropometry can be a solution to minimize awkward postures and risks accordingly.

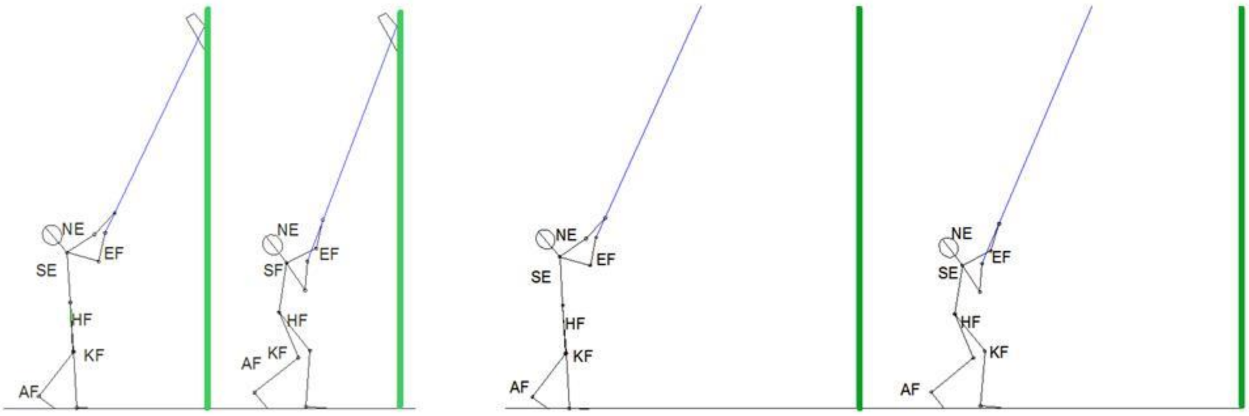


(a) D1: to harvest less than 2 m height FFB ***(b) D2: to harvest 2 – 3 m height FFB***

Figure 9 Schematic postures in the 'push cutting' techniques with a *Dodos* tool

The "pull cutting technique" is applicable to cut FFB on the palm tree with a height more than 3 m by using an *egrek* tool attached to a telescopic steel-pole. The awkwardness of arms, legs and trunk postures varied depending on the height position of FFB, the length of the tool's pole and the working distance of the worker to the tree. The average score of Posture A was4, 7 and 9 for FFB height of 3 – 6 m (E1), 6 – 12 m (E2) and > 12 m (E3), respectively; while the average score of Posture B was 7, 8 and 9, accordingly. The score of muscle use was 1 and force load was 4 (about 10 kg equivalent) for all cases. Thus, the Total Score of Group A became 8, 11 and 13; while the Total Score of Group B was 11, 12 and 13, respectively for E1, E2 and E3. These scores are extremely high according to the RULA scale; however, the Final Score 7 was finally resulted in all observed cases.

Figure 10 shows a schematic representation of workers posture when performing the E1 and E2 tasks. Upper arm flexion were always in 90°+, shoulder raise, lower arm abduction/adduction, wrist extension and twist were mostly required when work with higher cutting target (E2 or E3). Excessive neck extension was always observed as well. Back, hip, knee and ankle flexions were required to support muscle use and force load to pull and keep balance the long tool's pole to cut a big FFB located on a high palm tree. Neck, shoulder and arm were obviously in very awkward posture. Therefore, an immediate change is needed by re-designing the harvesting procedure in which appropriate working distance and length of the pole that suited to the workers anthropometry have to be fully considered to minimize the awkward posture and the risk accordingly. However, to fully eliminate awkward posture for the E2 and E3 tasks seems to be very difficult.



(a) E1: to harvest 3 – 6 m height FFB (b) E2: to harvest more than 6 m height FFB

Figure 10 Schematic postures in the 'pull cutting' techniques with an *Egrek* tool

Based on above mentioned work motion simulations and discussions, the awkward postures associated to the FFB harvesting tasks are generally resulted by combination of factors, such as: anthropometry of the worker, the height of the FFB targeted, length of the tool and the working distance (between the body and tree) in the workplace. Hence, work procedures should be designed to prevent – or at least to minimize – awkward postures in the harvesting tasks, especially on the neck extension, shoulder flexion and elevation, back extension and elbow flexion. Thus, the Author suggests such working procedure as follows:

(a). The "Push-cutting" technique for Dodos tool is recommended only for harvesting FFB less than 3 m height, whereas the "Pull-cutting" technique with Egreks tool must be applied to harvest FFB located on 3 m height or more. However, an appropriate length of tool's pole suitable for the worker's anthropometry and heigh of the harvesting target is required (see Table 3).

(b). Set body posture in front of the palm tree in such way that the cutting direction as can as possible in a line to the sagittal plan of the trunk, so side-bending and twisting of trunk can be minimized and the body weight can be stably and equally distributed on the legs.

(c). Set appropriate working distance (distance between the body to the targeted tree), so excessive neck and back extension can be minimized at first. In general, the appropriate working distance can be geometrically calculated as it is shown in Figure 11, especially for target height more than 3m. However, for safety reason, working distance should be not less than 1.5 m.

(d). Set 30° as the maximum neck extension (max NE) and 90° as the maximum shoulder flexion (max SF to avoid shoulder raised) as a benchmark of 'the most extreme' work posture. Thus, the minimum requirement of working distance (Dt in meter) can be geometrically calculated as: $Dt = 0.35 + (Ht - Hs)\sin \Theta$ (see Figure 12). By taking account the highest possible risk of the workers, 5th percentile arm dimensions (upper arm length=28 cm and forearm-grip length=29 cm) and shoulder height (124 cm) are concerned, 26° was resulted as the minimum value of Θ (Θ will be greater when NE is lesser). Thus, the recommended working distance can be simply calculated as: $Dt = 0.44Ht - 0.2$ (Ht is the height of targeted FFB and Dt is the minimum working distance, both in meter).

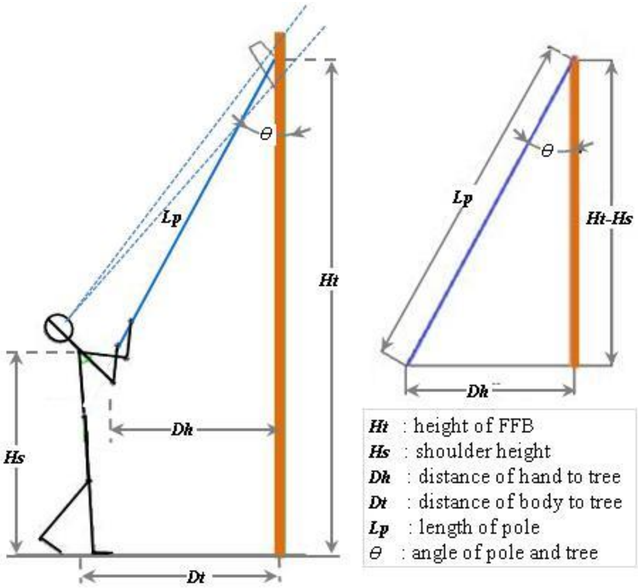


Figure 11 Geometrical illustration to calculate appropriate working distance and length of tool's pole in the manual harvesting tasks of oil palm

(f). Set appropriate length of tool's pole so it not too short to make excessive shoulder flexion, especially when harvesting FFB on a high position. As it is geometrically illustrated in Figure 11, the appropriate length of tool's pole can be calculated as: Lp = (Ht - Hs) cos-1 ϴ. By taking account 5th percentile body dimensions and 26 ° of ϴ, thus the recommended length of the tool's pole can be simply calculated as: Lp = 1.1 (Ht – 1); Lp is the length of the tool's pole in meter. However, for safety reason, the minimum length of the tool's pole should be not less than 1.5 m.

(g). Generaly for practical use in the field, minimum requirement of working distance and thengtth of the tool's pole that safely suitable to certain height of FFB targeted is recommended as presented in Table 3. However, harvesting of FFB height >12 m is very risky and cumbersome, so it is recommended that to harvest it manually with the present technique should be changed immediately.

Table 3 Required working distance and tool's length suited to certain height of FFB

Height of FFB (harvesting target)	Required Working Distance (minimum)*	Required Length of Tool's Pole (minimum)*	Harvesting Tool	Harvesting Technique
< 2 m	1.5 m	1.5 m	*dodos*	push
2 – 3 m	1.5 m	2.2 m	*dodos/egrek*	push/pull
4 m	1.6 m	3.3 m		
5 m	2.0 m	4.4 m		
6 m	2.4 m	5.5 m		
9 m	3.8 m	8.8 m	*egrek*	pull
12 m	5.1 m	12.1 m		
15 m	6.4 m	15.4 m		
18 m	7.7 m	18.7 m		

Note: *) Calculated for the minimum requirement based on 5th percentile body dimension to ensure that allpossible risks are concerned.

5 Conclusions

This study shows that FFB harvesting is a strenuous, heavy and labour intensive work, and therefore it is ergonomically risky. The results of motion analysis show that the upper body - especially the neck, shoulders and back – bear relatively extreme motions and awkward postures, and therefore it is high risky in term of work safety and MSD. Furthermore, RULA scores indicate that the work posture in most cases of the observed harvesting tasks were in the category of "Action Level 4", which means investigation and change is required immediately.

Data of anthropometry, work motions and postures of harvesting workers in three regions of oil-palm plantation in Indonesia were collected, summarized and discussed. This database is very essential and beneficial to enable us to design, adjust or modify the tools, equipment and work procedures in the agro-industrial operations – especially in the oil-palm industries – to improve the system performance and efficiency along with safety and comfort, as well as to prevent occupational accidents or injuries.

Formulation of task procedure and tool dimension that suited to the anthropometry of the worker believed can improve the task performance as well as to reduce awkward posture and prevent MSD risks. Motion simulations revealed that the dimensions of the stature, shoulder height and arms of the worker, length of the tool, and height of FFB targeted and the working distance are the essential variables in designing a good and safe harvesting task. Finally, good practices of the harvesting tasks have been developed which may beneficial to minimize awkward posture and MSD risk, and to improve work safety and productivity.

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