Operator workload analysis on coconut tree climbing using portable coconut climbing equipment

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Abstract. Recently, the work of climbing coconuts, especially in Aceh Province Indonesia still uses traditional methods, namely by climbing coconut trees directly. Traditional climbing is very high risk because it can fall which threatens the safety of life. Besides that, this job is also a heavy work category because it requires a lot of energy to do it. Therefore, the analysis of operator workload on climbing coconut trees using portable coconut climbing equipment is expected to be useful for developing tool designs and methods for climbing coconuts that are safer, more comfortable and more effective. The calculation of the operator's workload is based on heart rate measurements, where three operators have their heart rate data taken during coconut tree climbing activities, either manually or using portable climbing tools. The workloads analyzed are qualitative and quantitative workloads. The results of the workload analysis indicate that climbing is traditionally classified as a "medium" job with an average IRHR value of 1.45, while using portable climbing equipment is classified as heavy work with an IRHR value of 1.54. The traditional climbing energy consumption rate is 3.29 kcal/hour.kg-ow (kilocalories per hour per operator's weight), while using a portable climbing equipment is 3.82 kcal/hour.kg-ow. The high level of operator workload is largely determined by the operator's habits in doing climbing as well as skills that must be trained in operating the tool. However, in terms of operator safety, the use of portable equipment has a higher level of security because there are footrests and handrails as well as seat belts.

1. Introduction
In Aceh Province, coconut plantations are a regional flagship commodity involving 178,928 farming families or 894,640 people (28\%) of the 3.2 million population. The area of coconut plantations in Aceh Province in 2010 was 101,751 ha consisting of immarure pants 0,657 ha (10.47\%) [1]. The coconut plant lives in the tropics which is one of the unique plant products because in addition to the components of the fruit flesh which can be directly consumed, the fruit water can also be drunk directly without going through processing. This uniqueness is supported by the physical properties and chemical composition of coconut meat and water, so that this product is very popular with consumers, both children and adults.

In addition, from an economic point of view, almost all coconut plants can be used to add to the economic value of the community, ranging from coconut husks, shells, sticks to coconut trunks which
can be used as an alternative to bridges. The method of picking coconuts is very dependent on the height of the tree where the coconuts are located and in general they are climbed manually, namely by hand picking. In the first years, picking coconuts is usually done by hand directly without climbing the tree. If it is high and difficult to reach by hand directly, picking is usually done with a sickle or sickle. If it is higher (more than 2 meters above ground level) and difficult to reach by hand or sickle, the picking must be done by climbing the tree, then the fruit bunches are cut using a sharp sickle or sickle so that the fruit easily falls and comes off from the stalk [2].

Climbing coconut trees has a big risk because the coconut trees that are climbed reach tens meters height [3]. Coconut fruit pickers not only climb trees, reach for leaves and fruit, but pickers must have a trained instinct in determining which fruit is ripe enough to be harvested and which can be produced [4]. To facilitate climbing, the coconut trunk is made of kowakan or levels with a distance of 0.5 meters. The wounds of this kowakan or level must be cleaned frequently so that they do not rot so that the coconut trunk does not quickly become porous or become a nest of Kwangwung pests [5].

Therefore, several coconut climbing tools have been designed that can help in doing the work of picking coconuts. Several studies on coconut tree climbing equipment that have been carried out include Handoko S [5], the design tool still has shortcomings, namely in terms of safety and also not fast when climbing. Then the coconut tree climbing tool made by Somantri [6], still has weaknesses in terms of safety and security and is limited to straight coconut tree trunks, even though not all coconut tree trunks are perfectly straight. The climbing tool was later improved by Sardino et al. [7] namely a portable coconut climbing equipment, in this equipment coconut climbing can be done by people who are not experts in climbing so that it can provide user convenience. With this equipment, coconut farmers can climb coconuts many times compared to climbing coconuts traditionally. However, in terms of safety, comfort, health and safety of users, it has never been tested.

The objective of this study is to analyze the operator's workload level on coconut climbing using portable coconut climbing equipment and compare it with traditional or manual climbing methods, so that it is expected to be useful for developing equipment designs and methods of coconut climbing that are safer, more comfortable and effective.

2. Materials and methods

The tools used in this research are a portable coconut climbing equipment, heart rate monitor (HRM), digital metronome, step test bench, scales, meter, caliper, ruler, stopwatch, thermometer, time study sheet, handycam, Studio Plus software, and computer. The subjects observed for analysis on coconut climbing activities and their heart rate responses were coconut climbing farmers in Labuy Village, Aceh Besar District. Male, healthy, totaling 3 people, and aged 25-35 years. The coconut trees used are relatively old trees with a height of 6 to 10 meters.

According to Sardino et al. [7] the working principle of a portable climbing equipment is that this tool works based on the force of gravity to create a trapping effect on coconut trees. This tool consists of 2 (two) tools that are attached directly to the coconut tree. One for the left foot and hand, the second for the right leg and arm. When the right leg is lifted up while the hands are working to lift the tool up, at this time the steel cable will stretch and not entangle the coconut tree, making it easier for the tool to be moved up. If the foot starts to step on the snare of the steel cable will react so that it binds strongly to the coconut tree. Then followed by the left hand and foot alternately so that the equipment will work like a ladder.

2.1 Basal Metabolic Energy Measurement (Basalt Metabolic Energy/BME)

BME is the energy consumption needed to carry out minimal physiological functions. The method commonly used to determine the BME value is to calculate body dimensions using the Du'Bois equation [8]:

$$ A = H^{0.725} \times W^{0.425} \times 0.007246 $$  \hspace{1cm} (1)
where:  
\[
A = \text{Body surface area (m}^2) \\
H = \text{height (cm)} \\
w = \text{body weight (kg)}
\]

BME (equivalent to VO2) can be determined using the conversion table shown by the Conversion Table for BME equivalent to VO2 based on body surface area according to Sumanjiru in Syuaib [8].

2.2 Quantitative workload measurement

Data retrieval begins with the collection of heart rate measurement calibration data using the Step Test (ST) calibration method using HRM. The rhythmic pace of the steps measured at a frequency of 20, 25, and 30 cycle/s/minute. Then the Work Energy Cost (WEC) for each ST cycle is calculated by the equation:

\[
WEC_{ST} = \frac{w \times g \times 2f \times h}{4.2 \times 10^3}
\]

where:

- \(WEC_{ST}\) = Work Energy Cost during step test (kcal/minute)
- \(w\) = body weight (kg)
- \(g\) = acceleration due to gravity (9.8 m/s²)
- \(f\) = step test frequency (steps/minute)
- \(h\) = height of the step test bench (meters)
- 4.2 = unit calibration factor from Joules to calories

The subjectivity of the heart rate (HR) value of CST results must be normalized in order to obtain a more objective HR value for each subject observed. Normalization was carried out by comparing the relative HR at ST (HR
\[\text{ST}n\]) to HR at rest. This comparison value is called the Increase Ratio of Heart Rate (IRHR).

\[
IRHR_{\text{step test}} = \frac{HR_{\text{ST}}}{HR_{\text{rest}}}
\]

Next, a graph is made to see the correlation to the increase in \(WEC_{ST}\) which has equation:

\[
Y = aX + b
\]

where : \(Y = IRHR\) and \(X = WEC\) (kcal/minute)

The subject's IRHR value in climbing activities is entered into the subject's equation as 'Y' so that the 'X' value is obtained as work energy consumption when climbing (work WEC). Then the Total Energy Cost (TEC) can be calculated.

\[
TEC = WEC + BME
\]

where :

- \(TEC\) = Total Energy Cost (kcal/minute)
- \(WEC\) = Work Energy Cost (kcal/minute)
- \(BME\) = Basal Metabolic Energy (kcal/minute)

The subject's body weight will affect the body surface area and will increase the workload when calculating TEC', so to minimize TEC divided by body weight.

\[
TEC' = \frac{TEC}{w}
\]
TEC' = Work Energy Cost per Weight (cal/kg.minute)
\( w \) = body weight (kg)

2.3 Qualitative workload measurement
This workload measurement is done by looking at the level of a person's workload based on the IRHR value, it can be seen in the job category table based on the IRHR according to Syuaib [8].

3. Results and discussion
Climbing is done by 3 different operators, in Figure 1 shows coconut climbing is done traditionally, while in Figure 2 it can be seen that climbing is done using a portable climbing equipment. From Figure 1, it can be seen that from a safety point of view, traditional climbing is very risky because the weight is on the hands and feet. If a slip occurs due to a slippery rod, there is a risk of an accident.

While in Figure 2, the operator's weight is already on the portable climbing equipment, so the risk of accidents can be minimized. Even the climbing equipment is also equipped with a safety belt, so that even if there is a slip on the foot and hand grips, there is still additional security.

![Figure 1. Traditional/manual coconut climbing, (a) operator 1, (b) operator 2, (c) operator 3.](image1)

![Figure 2. Climbing coconuts using portable climbing equipment, (a) operator 1, (b) operator 2, (c) operator 3.](image2)

3.1 Basal Metabolism Measurement (BME)
BME measurement is the first step in calculating workload, because it will know the energy consumption required by the subject to carry out his minimal physiological functions. In the following, the results of measuring body dimensions and BME of each subject are presented (Table 1).
### Table 1. Anthropometric characteristics and Basal Metabolism Measurement (BME) values of each subject.

| Subject  | Sex   | Age | Weight (kg) | Height(cm) | A (m²) | BME (kcal/min) |
|---------|-------|-----|-------------|------------|--------|----------------|
| Operator 1 | Man  | 20  | 48          | 160        | 1,49   | 0,92           |
| Operator 2 | Man  | 18  | 50          | 159        | 1,51   | 0,935          |
| Operator 3 | Man  | 26  | 58          | 170        | 1,69   | 1,045          |

### Table 2. Increase Ratio of Heart Rate (IRHR) number dan WEC<sub>ST</sub> subject at CST.

| Subject  | ST1 (20 cycle/min) | ST2 (25 cycle/min) | ST3 30 cycle/min) |
|---------|--------------------|--------------------|--------------------|
|         | IRHR               | WEC<sub>ST</sub>   | IRHR               | WEC<sub>ST</sub>   | IRHR               | WEC<sub>ST</sub>   |
| Operator 1 | 1,32               | 1,34               | 1,42               | 1,68               | 1,57               | 2,02               |
| Operator 2 | 1,36               | 1,40               | 1,50               | 1,75               | 1,70               | 2,10               |
| Operator 3 | 1,31               | 1,62               | 1,36               | 2,03               | 1,41               | 2,44               |

### Table 3. Calibration and Work Energy Cost (WEC) equations during manual climbing.

| Subject  | Calibration equation \(y = IRHR; x = WEC\) | IRHR work | WEC work (kcal/min) |
|---------|---------------------------------------------|-----------|---------------------|
| Operator 1 | \(y = 0.2721x + 0.9855\) | 1,34       | 1,29                |
| Operator 2 | \(y = 0.315x + 0.9759\) | 1,77       | 2,53                |
| Operator 3 | \(y = 0.1716x + 1,0092\) | 1,39       | 2,24                |
| Average  |                                    | 1,50       | 2,02                |

### Table 4. Calibration and Work Energy Cost (WEC) equations when climbing using equipment.

| Subject  | Calibration equation \(y = IRHR; x = WEC\) | IRHR work | WEC work (kcal/min) |
|---------|---------------------------------------------|-----------|---------------------|
| Operator 1 | \(y = 0.2721x + 0.9855\) | 1,43       | 1,64                |
| Operator 2 | \(y = 0.315x + 0.9759\) | 1,74       | 2,44                |
| Operator 3 | \(y = 0.1716x + 1,0092\) | 1,55       | 3,15                |
| Average  |                                    | 1,58       | 2,41                |

### Table 5. Qualitative and quantitative workload of manual climbing activities.

| Subject  | Weight (kg) | IRHR work Workload (kcal/min) | BME (kcal/min) | WEC (kcal/min) | TEC (kcal/min) | TEC’ (kcal/kg.hour) |
|---------|-------------|--------------------------------|----------------|----------------|----------------|---------------------|
| Operator 1 | 48          | 1,34 Medium Very | 0,92           | 1,29           | 2,21           | 2,76                |
| Operator 2 | 50          | 1,77 Heavy     | 0,935          | 2,53           | 3,47           | 4,16                |
| Operator 3 | 58          | 1,39 Medium    | 1,045          | 2,24           | 3,28           | 3,40                |
| Average  | 52          | 1,50 Heavy     | 0,97           | 2,02           | 2,99           | 3,44                |

### Table 6. Qualitative and quantitative workloads of climbing activities using equipment.

| Subject  | Weight (kg) | IRHR work Workload (kcal/min) | BME (kcal/min) | WEC (kcal/min) | TEC (kcal/min) | TEC’ (kcal/kg.hour) |
|---------|-------------|--------------------------------|----------------|----------------|----------------|---------------------|
| Operator 1 | 48          | 1,43 Medium Very | 0,92           | 1,64           | 2,56           | 3,20                |
| Operator 2 | 50          | 1,74 Heavy     | 0,935          | 2,44           | 3,37           | 4,04                |
| Operator 3 | 58          | 1,55 Heavy     | 1,045          | 3,15           | 4,20           | 4,34                |
| Average  | 52          | 1,58 Heavy     | 0,97           | 2,41           | 3,38           | 3,86                |
3.2 Measurement of IRHR, WEC, IRHR Work and WEC work

Step Test Calibration (CST) was conducted to determine the correlation between heart rate and increased workload. Each subject has different characteristics and physiological abilities (cardiovascular ability and muscle fiber) are different. The WECST value, which is the value of the subject's energy consumption for the body's metabolic processes and doing work, needs to be calculated to make graphs and power equations with IRHR values. While the WECST value can be calculated using the power principle approach. It is assumed that at the time of the step test the subject was walking up the stairs carrying a load of his own body weight (Table 2). The relationship between WECST and IRHR is then plotted in a graph. Each subject has its own slope of the graph that represents the increase in IRHR against the increase in the WECST value.

From the graph, it can be seen that the steeper the slope of the line, the greater the change in the IRHR value to changes in the level of workload. The graph has a maximum limit for IRHR and WEC values. The maximum limit depends on the maximum heart capacity of each subject.

Table 3 presents the WECST and IRHRST calibration equations and the amount of energy expended when working (climbing). To find out the work energy released by the subject (WEC) in land preparation activities using a tread, it is done by inputting the IRHR value for the activity into the correlation equation between IRHR and WEC work (Table 3).

The result of measuring heart rate when climbing manually (IRHR Work) is 1.34-1.77, while using a portable climbing equipment is 1.43-1.74. So by entering this value into the equation (as y), the energy released by the subject when climbing traditionally is 1.29 – 2.53 kcal/min and using a portable climbing equipment is 1.64 – 3.15.

3.3 Qualitative and quantitative workload

Qualitative workload analysis was carried out to see the level of workload level (grief) relative to the physiological condition of the subject. While the quantitative workload to see the amount of energy released by the subject at work. Table 5 shows the results of qualitative and quantitative analysis of 3 subjects in traditional climbing, while Table 6 shows climbing using portable climbing equipment.

The results of the qualitative analysis show that the average IRHR of traditional climbing work is between 1.34 - 1.77, so that the workload on climbing activities is 'Medium' - 'Very Heavy' with an average work of 'Heavy'. Meanwhile, for climbing using portable climbing equipment, the IRHR work is 1.43 – 1.74, with the category 'Medium' – 'Heavy' with an average workload of 'Heavy'. When compared with research [9] on manual oil palm harvesting activities, the level of workload or workload Physical subjects based on IRHR values for all work sub-systems are in the interval from 1.70 to 2.15 with a workload classification of 'medium' to 'very heavy'. Meanwhile, research [10-12] shows that the operation of a two-wheeled tractor is classified as a 'heavy' workload caused by the magnitude of the forces required by the operator to move the tractor control devices.

The total work energy per body weight (TEC') for traditional climbing is between 2.76-4.16 kcal/kg.Hour and an average of 3.44 kcal/kg.Hour. Meanwhile, climbing using a portable climbing equipment 'TEC' is between 3.20-4.34 kcal/kg.hour and an average of 3.86 kcal/kg.hour. The magnitude of the workload experienced by operators who use portable climbing equipment is greater than with manual climbing because the operators are not accustomed to using climbing equipment, while they are very proficient in traditional climbing which affects their mental workload. Besides that, in climbing using equipment, the operator must expend energy to lift the climbing equipment which weighs approximately 7 kg.

However, the use of this portable climbing equipment has a higher level of safety, where the operator can support the weight of the body on the footrest and the handle on the climbing equipment so that it does not require a lot of force to support it. In addition, the tool is equipped with a safety belt that can reduce the risk of falling for the operator, if there is a slip on the foot and hand support. In
research [7] on the use of portable climbing equipment, climbers were more free to use both hands in cleaning the coconut canopy and picking it because the body was supported/retained by a seat belt.

4. Conclusions

The qualitative workload level of three climbers on traditional coconut tree climbing is between 'Medium' - 'Very Heavy', while using portable climbers is in the 'Medium' – 'Heavy' category. Meanwhile, the level of quantitative workload for three operators on traditional coconut tree climbing with energy consumption levels per body weight of 2.76-4.16 kcal/kg.Hour, while using a portable climber the workload level is 3.20-4.34 kcal/kg.Hour. The qualitative and quantitative load levels are influenced by the operator's work experience and the weight of the portable climbing equipment. Although the level of workload of climbing using portable climbing tools is the same as manual climbing, the use of this climbing tool has a higher level of safety and comfort, because it is equipped with footrests, handrails and seat belts.

References

[1] Aceh B P S 2010 Aceh dalam angka Badan Pusat Statistik Aceh. Banda Aceh
[2] Nugroho I 2006 Perancangan alat pemanjat pohon kelapa penggerak manual PhD Thesis (University of Muhammadiyah Malang)
[3] Mani A and Jothilingam A 2014 Design and fabrication of coconut harvesting robot: COCOBOT International Journal of Innovative Research in Science, Engineering and Technology 3
[4] Abraham A, Girish M, Vitala H R and Praveen M P 2014 Design of harvesting mechanism for advanced remote-controlled coconut harvesting robot (arch-1) Indian journal of Science and Technology 7 1465
[5] Handoko S 2013 Penciptaan alat panjat pohon kelapa Jurnal Riset Daerah, XII (2)
[6] Somantri H 2015 Rancang Bangun Mesin Pemanjat Pohon Kelapa Bandung: Universitas Pasundan
[7] Sardino S, Ilham H A, Saputra A, Syahta R, Herdian F and Jamaluddin J 2018 Rancang bangun alat panjat kelapa portable Journal of Applied Agricultural Science and Technology 2 72–82
[8] Syuaib M F 2003 Ergonomic study on the process of mastering tractor operation PhD Thesis (東京農工大学)
[9] Dewi N S and Syuaib M F 2012 Workload Analysis on Oil-Palm (Elaeis guineensisJacq) Harvesting Activity in Oil-Palm Plantation in West Sulawesi, Indonesia
[10] Dhafir M 2002 Analisis biomekanik, studi gerak dan waktu pada pengoperasian traktor tangan Master Thesis (Indonesia: Institut Pertanian Bogor)
[11] Yunus Y, Devianti, Satriyo P and Munawar A A 2019 Rapid Prediction of Soil Quality Indices Using Near Infrared Spectroscopy IOP Conference Series: Earth and Environmental Science vol 365 (Institute of Physics Publishing)
[12] Dhafir M, Safrizal, Idkham M and Munawar A A 2021 Motion and postural risk analysis for agricultural soil pivot type trailer hitching system on two-wheel tractor IOP Conf. Ser. Earth Environ. Sci. 644 012029