Analysis of working load of semi-automatic sprayer knapsack operators on spraying at paddy fields

by Ansar Ansar

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Abstract. The use of a knapsack sprayer for pest and disease control is quite exhausting, causing fatigue for operators. This fatigue can cause pain or injury to the muscles. Therefore, this study aimed to determine the operator's workload based on fatigue and total energy consumption in operating the knapsack sprayer. There are 2 types of knapsack sprayer equipment, namely high-density polyethylene sprayer (HDPS), and stainless steel sprayer (3S). The results show that the operator's workload is in light of the moderate category as indicated by the average IRHR value for HDPS between 1.063-1,580 and 3S between 1,194-1,687. Calculation of the operator's workload obtained an average value of total energy consumption for HDPS between 0.034-0.078 kcal/kg, while 3S between 0.046-0.087 kcal/kg. The normalized work energy consumption value of the HDPS operator between 1.367-3.554 kcal/kg, while 3S between 1.954-4.234 kcal/kg. Based on the calculation of the total score of each operator, it is known that the level of muscle complaints using the HDPS or 3S shows did not differ significantly. However, the workload of using HDPS is lower than the 3S at a capacity of 8-14 litters.

1. Introduction

Indonesia is an agricultural country that relies on income from the agricultural sector, which is characterized by the highest livelihood of its population from the agricultural sector, which is 35,923,886 people (Ansar et al., 2020). However, on the other hand, this sector has many obstacles and often experiences crop failure due to sub-optimal cultivation and plant pests (Ansar, 2011). The average weed attack on cultivated agricultural land has a cover between 30-40% per hectare per year, while the area of agricultural land in Indonesia is around 13 million hectares (Ansar et al., 2020), so we can estimate the amount of weed cover as a whole can reach 5.2 million hectares per year. This condition is, of course, the main factor inhibiting efforts to increase agricultural output. The disadvantage of pest and disease attacks is that they can reduce crop yields, and can even thwart crops (Choi et al., 2013). To overcome this problem, farmers generally apply anti-pest substances or pesticides to their cultivated crops (Wong and Brown, 2020).

There are several kinds of methods of applying pesticides, one of which is spraying (Gutgesell et al., 2020). Knapsack sprayer is an agricultural tool that functions to spray pesticide solutions on cultivated plants (We et al., 2012). The sprayer that is most in demand by the middle to lower-middle farmers is the knapsack sprayer because it is cheaper, easy to use, and very suitable for narrow land conditions (Garcia-Santos et al., 2020). The application of pipelines for fertilizers and pesticides is considered less

effective for their application on agricultural land in Indonesia. Apart from having high prices and maintenance costs, generally, the size of agricultural land plots in Indonesia is also relatively narrow, farmers' low capital and strong cultural influences have made the use of these installations not widely used by Indonesian farmers (Syuaib, 2015). Traditional agricultural tools will still be used for a long time (Ansar et al., 2020).

Therefore, studies on these tools still need to be carried out. The use of a knapsack sprayer in controlling pests and diseases is quite draining, wherein operation, the operator acts as a controller or the main source of energy so that it often creates a physical burden on the operator (Li, 2019). Meanwhile, according to Garcia-Santos et al. (2020), the problem that is often experienced by farmers in operating a knapsack sprayer has to walk while carrying the weight of this sprayer, which reaches 15-20 kg. This problem seems simple, it is just that if the spraying work is carried out on a relatively large area of land and for a long time, it will increase the operator's workload, which results in lowering motivation and comfort at work (Ren et al., 2019).

Therefore, this research is very important to do to determine the workload of workers. By knowing the operator's workload, it is hoped that the operator can pay more attention to comfort while doing their job, so that pressure, fatigue, and work accidents on the operator can be minimized. Based on this description, the purpose of this study is to analyze the workload of the knapsack sprayer operator on land spraying in paddy fields.

2. Methodology

2.1 Research tools and materials

The tools used in this research are knapsack sprayer type high-density polyethylene sprayer (HDPS), and stainless steel sprayer (3S), pulse measuring instrument, digital metronome, step test bench, roll meter, stopwatch, body scale, and measuring instrument.

2.2 Research parameters

The parameters used in this study are:
1. Workability
2. Total energy consumption
3. Work energy consumption

2.3 Research parameters

The research was carried out in the following stages:
1. The subjects selected for this spraying activity were 3 male farmers from Perian Utara Village, Montong Gading District, East Lombok Regency with a height between 160-168 cm, according to the anthropometric range of Indonesians aged 20-35 years.
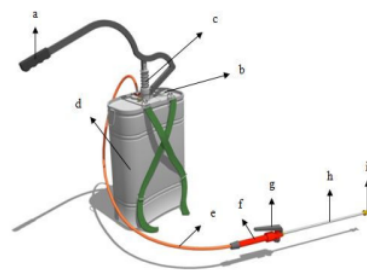2. Determine the type of sprayer used in the study (figures 1 and 2).

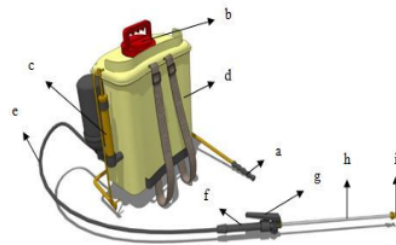**Figure 1**. Knapsack sprayer type of stainless steel sprayer (3S).

Figure 2. Knapsack sprayer type high-density polyethylene sprayer (HDPS).

Annotation:
- a. Pump grip
- b. Close the tank
- c. Pump
- d. Sprayer Tank Supply Hose
- e. Spray grip
- f. Faucet (valve) Spray
- g. Nozzle pipe
- h. Nozzle

3. Measurement of Basal Metabolic Energy (BME), which is the energy consumption required to carry out the spray by calculating the dimensions of the body using the DuBois equation (Syuaib, 2015):

$$A = H^{0.275} \times W^{0.425} \times 0.00724 \qquad (1)$$

Where, A = body surface area (m2), h = height (cm), and W = body weight (kg).

4. Measuring the qualitative workload by looking at the level of operator workload based on the IRHR (Increase Ratio of Heart Rate) value with the equation:

$$IRHR = \frac{RH_{work}}{RH_{rest}} \qquad (2)$$

Where, RHwork = pulse at activity, RHrest = pulse at rest.

5. Measuring the quantitative workload begins by taking the calibration data of the heart rate measurement using the step test method. The pace of the steps is measured at a frequency of 20, 25, and 30 cycles/minute. Furthermore, the work-energy consumption of the operator step test (WECST) can be calculated by the equation:

$$WEC_{ST} = \frac{w \times g \times 2f \times h}{(4.2 \times 10^3)} \qquad (3)$$

Where, WECST = work energy cost during the step test (kcal / minute), W = body weight (kg), g = acceleration of gravity (m / s2), f = frequency of step test, steps/minute), h = height of step bench test (m), 4.2 = unit conversion factor from joules to calories.

The subjectivity of the heart rate value from the calibration step test must be normalized to obtain a more objective pulse value. Normalization is done by comparing the operator's pulse during the step test and at rest. This comparison value is called the Increase Ratio of Heart Rate (IRHR), which can be calculated by the equation:

$$IRHR_{ST} = \frac{RH_{ST}}{RH_{rest}} \qquad (4)$$

Then a graph is made to see the correlation to the increase in WECST, which can be calculated with the DuBois equation (Syuaib, 2015):

$$y = ax + b \qquad (5)$$

Where, y = IRHR, x = WEC (kcal / min), a and b = constant.

The operator's IRHR value during spraying activities (IRHRWORK) is then entered into equation (4) to obtain the WECWORK value so that the total value of the operator's energy consumption when operating the sprayer can be calculated:

$$TEC = WEC + BME \qquad (6)$$

Where, TEC= total energy cost (kcal/minute), WEC = work energy cost (kcal/minute), and BME = basal metabolic energy (kcal/minute).

Operator weight becomes a separate burden when doing spraying activities because it will affect the body surface area, thus increasing the workload on the TEC's calculation. Then to minimize it, the TEC is divided by the weight of the worker.

$$TEC' = \frac{TEC}{W} \qquad (7)$$

Where, TEC' = Normalized TEC (kcal / kg), TEC = total energy cost kcal/minute), w = body weight (kg).

2.4 Data analysis
The research data were analyzed using analysis of variance and the Tukey's HSD test (Tukey's Honestly Significant Difference Test) to determine the effect of the type of sprayer on the workload and energy consumption of operators (Ansar et al., 2020).

3. Result and Discussion
3.1 Calibration of the subject's step test
The subject calibration of the step test method is carried out to determine the characteristics of the heart rate of each individual while doing a job. Each individual's response to a job will not be the same. This is due to several factors such as the different physical and psychological conditions of the individual. The calculation of the WEC value during the step test also needs to be done. WECST is the rate of energy consumption when the subject performs a step test. The WECST values and IRHRST values obtained (Table 1) were then plotted into a linear graph, to obtain the power equation for each subject.

Table 1. Operator's WEC value when spraying

Subject	8 L IRHR	Qualitative workload	11 L IRHR	Qualitative workload	14 L IRHR	Qualitative workload
	Stainless Steel Sprayer					
A	1.174	Light	1.366	Moderate	1.606	Moderate
B	1.221	Light	1.529	Moderate	1.788	Heavy
C	1.188	Light	1.471	Moderate	1.667	Moderate
Average	1.194	Light	1.455	Moderate	1.687	Moderate
	High-Density Polyethylene Sprayer					
A	1.030	Light	1.127	Light	1.486	Moderate
B	1.116	Light	1.333	Moderate	1.696	Moderate
C	1.044	Light	1.246	Light	1.559	Moderate
Average	1.063	Light	1.235	Light	1.580	Moderate

Table 1 shows that each operator has a different power equation. This power equation is used to estimate the WEC value of the operator when spraying (WECWORK), namely by substituting the working IRHR (IRHRWORK) value obtained from equation (4).

3.2 Qualitative workload
Qualitative workload measurement is carried out to determine the level of workload (fatigue) of the subject in spraying. Based on Table 2, it can be seen that the average IRHR value of the subject's work when operating the two sprayers is different. The IRHR value of 3S subjects was higher than the IRHR value of HDPS subjects. The IRHR 3S value was between 1.194-1.687, while the IRHR HDPS value was between 1.063-1.580.

Table 2. The results of Tukey's HSD test of operator fatigue

Treatment	Average (%)		
	Solution volume		
	8L	11L	14L
3S	1.194^c A	1.455^b A	1.687^a A
HDPS	1.063^b A	1.235^b A	1.580^a A

Note: The numbers followed by the same letter in the row and column show no significant difference in Tukey's HSD test at the 5% significance level.

Although the IRHR of 3S subjects was higher than HDPS subjects, the workload level classification of both sprayers was classified as a "light" to "moderate" workload. This is because the rice fields used in this study are still in small plots, namely, 16 are, while farmers usually spray up to 1 hectare of land. Besides, the sprayer capacity used by farmers usually reaches 20 litters each way. While in this study only 8-14 litters of capacity are used. This is why the operator workload level when operating the two sprayers is classified in the workload level from "light" to "moderate". Similar research results have been reported by (Xiao et al., 2020) that spraying is a light category of work because the load that is carried is not too heavy.

The results of Tukey's HSD test analysis in Table 2 show that the type of sprayer does not have a significant effect on the fatigue level of workers at all sprayer capacities tested. This means that the 3S operating load is almost the same as operating an HDPS. The addition of the volume of the sprayer solution has a significant effect on worker fatigue. The results of Tukey's HSD test at the 5% significance level showed that the addition of the volume of the 3S solution from 11 to 14 litters both had a significant effect on worker fatigue. This means that the addition of the 3S solution volume of 3 litters is sufficient to prove a significant effect on operator fatigue.

While the use of volume from 8 to 11 liters does not have a significant effect on worker fatigue, but after adding the volume to 14 liters, it has a significant effect on the level of worker fatigue. This means that there is not enough evidence to show that the addition of a solution volume of 3 liters at an additional volume of 8 to 11 liters on HDPS has a significantly different effect on the level of operator fatigue (Table 3).

Table 3. Physical characteristics and BME values for each operator

Subject	Stainless Steel Sprayer								
	WEC$_{Work}$ (kcal/minute)			TEC (kcal/minute)			TEC' (kcal/kg)		
	8L	11L	14L	8L	11L	14L	8L	11L	14L
A	1.470	2.5082.	3.805	2.420	3.458	4.755	0.047	0.067	0.091
B	1.658	9262.5	3.992	2.653	3.921	4.987	0.050	0.074	0.094
C	1.322	68	3.432	2.362	3.608	4.472	0.040	0.061	0.076
Average							0.046	0.067	0.087
	High-Density Polyethylene Sprayer								
A	0.6921	1.2162	3.157	1.642	2.166	4.107	0.032.	0.042	0.079
B	226	1191.5	3.613	2.221	3.114	4.608	0.042	0.059	0.087
C	0.687	77	2.956	1.727	2.617	3.996	0.029	0.044	0.068
Average							0.034	0.048	0.078

3.3 Quantitative workload

Quantitative workload measurement is intended to determine the amount of energy expended by workers when spraying. The initial stage for determining the quantitative workload is by calculating the basal metabolic average (BME) of workers. By knowing BME, it can be seen the minimum energy consumption required by workers to carry out their minimum physiological functions. The BME value is influenced by the body dimensions (weight and height) of the worker. The BME value for each worker can be seen in Table 4.

Table 4. Data on spraying field capacity

| Subject | Stainless Steel Sprayer | | |
| | Land area/time (m²/minute) | | |
	8 L	11 L	14 L
A	46.811	44.236	40.424
B	30.552	29.515	27.383
C	38.807	36.101	33.841
Average	38.723	36.617	33.883
	High-Density Polyethylene Sprayer		
A	51.200	49.736	44.162
B	33.078	31.153	28.980
C	43.080	40.445	36.101
Average	42.453	40.444	36.415

The qualitative workload is known by looking at the total energy consumption (TEC) released by the worker during spraying activities. The TEC value for each worker is obtained by adding the BME value to the energy expended by the worker when spraying (WECWORK). The TEC value of each operator can be seen in Table 5. After the TEC value is obtained, the total work energy consumption of the operator (kcal/are) is determined by measuring the area of land resulting from the spray. This is done to determine the effect of the total energy consumption expended on the resulting work output.

Table 5. Operators' work energy consumption

| Subject | Stainless Steel Sprayer | | | | | |
| | Work energy consumption (kcal/are) | | | Normalized work energy consumption (kcal/kg) | | |
	8L	11L	14L	8L	11L	14L
A	82.715	125.075	188.203	1.591	2.405	3.619
B	138.937	212.557	291.390	2.621	4.011	5.498
C	97.385	159.906	211.436	1.651	2.710	3.584
Average				1.954	3.042	4.234
	High-Density Polyethylene Sprayer					
A	51.312	69.680	148.796	0.987	1.340	2.861
B	107.429	159.935	254.407	2.027	3.018	4.800
C	64.141	103.528	177.103	1.087	1.755	3.002
Average				1.367	2.037	3.554

Table 6 shows the average operator field capacity in using HDPS higher than 3S. HDPS operator's field capacity is high because the sprayer is lighter in weight and comfortable to operate so that the operator works relaxed and without being stressed. The empty weight of HDPS is 4.3 kg, while the 3S is 7 kg so that the difference in the weight of the two sprayers is 2.7 kg. This is also the main factor causing operators to experience more difficulties due to the burden of carrying the heavy sprayer while walking and the longer time required for field spraying using 3S. According to Wang et al. (2019), the difference in the field capacity of each operator in operating the knapsack sprayer is influenced by the operator's skill and response when operating the tool. The longer it takes the operator to spray a certain area of land, the smaller the operator's field capacity will also be.

Table 6. Tukey's HSD test results of work energy consumption of operator normalization

| Treatment | Average (%) | | |
| | Solution Volume | | |
	8L	11L	14L
Stainless Steel Sprayer	1.954[b] A	3.042[ab] A	4.234[a] A
High-Density Polyethylene Sprayer	1.367b A	2.037ab A	3.554a A

Note: The numbers followed by the same letter in the row and column show no significant difference to the Tukey's HSD test at the 5% significance level.

The results of Tukey's HSD test data analysis in Table 6 show that the type of sprayer does not have a significant effect on the operator's normalized work energy consumption at all sprayer capacities tested. This shows that there is not enough evidence to show that the operator's normalized work energy consumption when operating the 3S is higher than when operating the HDPS. The Tukey's HSD test results at the 5% level show that the addition of solution volume both at 3S and HDPS from volume 8 to 11 and 11 to 14 litters does not have a significant effect on the operator's normalized work energy consumption. This is presumably because the addition of a solution volume of 3 litters is not sufficient to provide a high burden on the normalized work energy consumption of 3S and HDPS operators. Yin et al. (2017) that work energy consumption can have a significant effect on operator workload if there is a high increase in load reported the same thing.

4. Conclusion

Spraying activities in paddy fields using SHDP and 3S are classified as light and medium workload classifications. The operator workload is qualitatively in the category of workload level from very light to moderate as indicated by the average IRHR value of HDPS workers between 1.063-1.580 and 3S between 1.194-1.687. In calculating the operator workload quantitatively, the average value of normalized total energy consumption for HDPS is between 0.034-0.078 kcal/kg, while 3S is between 0.046-0.087 kcal/kg. Based on the operator's workload, the use of SHDP is smaller than the 3S at a capacity of 8-14 liters. Spraying using 3S or HDPS based on operator workload shows no significant difference.

Acknowledgements

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