Ergonomic evaluation of battery operated knapsack sprayer

Shubham Zilpilwar[1], Rajvir Yadav[2*], Ketan Sakariya[3] ,Manisha Gahane[4]

(1.M. Tech, Dept. of Farm Mach. & Power Engg., Junagadh Agril. Uni., Junagadh, (GJ) India, 362001;
2.Professor & Head, Dept. of Farm Engg., Junagadh Agril. Univ., Junagadh, (GJ) India, 362001;
3.M. Tech, Dept. of Renewable Energy. Engg., Junagadh Agril. Uni., Junagadh, (GJ) India, 362001;
4.M. Tech, Dept. of Process & Food Engg., Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, (MH), India, 444101)

Abstract: Spraying is one of the most important operations in crop production to protect the crops from attack of various pest and diseases. Ergonomic intervention in spraying operation can provide a reasonable basis for the recommendation on operating methods and efficient operation for more output and safety. The ergonomic evaluation of the commercially available sprayers such as battery operated, power operated and lever operated knapsack sprayer was carried out on the basis of heart rate, oxygen consumption rate and energy expenditure rate. The rest pause, work load, musculoskeletal problems and overall discomfort rating in operators was determined. The average heart rate (HR), oxygen consumption rate (VO2) and energy expenditure rate (EER) of the subjects were 97.44 beats min^{-1}, 0.43 lit min^{-1}, 9.02 kJ min^{-1}; 102.66 beats min^{-1}, 0.49 lit min^{-1}, 10.26 kJ min^{-1} and 111.67 beats min^{-1}, 59 lit min^{-1}, 12.41 kJ min^{-1} respectively during spraying operation by battery operated, power operated and lever operated knapsack sprayer. Minimum heart rate, oxygen consumption rate, energy expenditure, light to moderate work load and very light overall discomfort occurred in operators body during spraying operation by using battery operated knapsack sprayer and it was less as compare to other two sprayers.

Keywords: Oxygen consumption rate, energy expenditure rate, rest pause, musculoskeletal problems, overall discomfort rating

Citation: Zilpilwar, S., R. Yadav, K. Sakariya, and M. Gahane. 2021. Ergonomic evaluation of battery operated knapsack sprayer. Agricultural Engineering International: CIGR Journal, 23(3): 182-189.

1 Introduction

Spraying is an important practice for crop protection from attack of various pest and diseases using chemical application. It is complex process and can be influenced by canopy geometry of plants, pesticides properties, and design of spray equipment, application parameters and weather conditions (Thread Gill and Smith, 1975).

Traditionally the hand lever operated knapsack sprayers used by the Indian farmers for spraying of liquid pesticides and continuous use of this sprayer causes fatigue in operators resulted into low efficiency. To overcome such problems, solar cum battery operated hybrid knapsack sprayer for vegetable crops was developed by using modern development techniques (Zilpilwar et al., 2018).

Tamilselvi and Krishnan (2016) carried out the study on ergonomic evaluation of conventional agricultural sprayers with respect to human performance. The ergonomic evaluation was carried on heart rate and oxygen consumption rate, energy cost of operation, grading energy cost of work, acceptable work load (AWL), limit of continuous performance (LCP), overall discomfort rating (ODR) and body part discomfort score (BPDS). They concluded that ergo refined sprayers provided better comfort and efficiency to the operator. Yadav and Pund (2007) developed manual weeder and its ergonomic evaluation was carried out in the groundnut crop, and they reported that the travelling speed during weeding operation depended on the weight,

Received date:2019-08-31 **Accepted date:**2021-04-26

***Corresponding author: Rajvir Yadav.** Ph. D., Department of Farm Engineering, Junagadh Agricultural University, Junagadh, Gujarat (India), 362001, Email: ryadav61@gmail.com, Mo +919426420561.

height and physical condition of the operator.

Gite et al., (1991) investigated on lever operated manual knapsack sprayer. The study indicated that though the workload in the spraying operation was within the acceptable limits according to the physiological criteria, and there was a need to make improvements in the mounting of the sprayer on the operator's back to reduce the postural discomfort. According to Gite, (1993) the performance of any manually operated machine/equipment could be improved if ergonomic aspects would be taking into consideration for design of particular machine. It also depends on the physical condition of the workers operating the machine.

Kumar and Parihar (2018) conducted the study on ergonomic evaluation of manually operated single row manual vegetable transplanter for three different types of vegetable crops and compare it with traditional method of transplanting on ergonomic basis and evaluate the energy expenditure rate for operation. Yadav et al., (2007) conducted the study on ergonomic evaluation of manually operated six row transplanters to work out the energy expenditure of male and female workers during transplanting by manually and machine.

The study of ergonomic evaluation of battery-operated sprayer was carried to check the suitability of developed sprayer for manual spraying operation with minimum drudgery and tiredness of the operator.

2 Materials and methods

During the okra crop spraying, the ergonomic evaluation of battery operated, power operated and lever operated knapsack sprayer were conducted. The experiment was carried out at research plot of Vegetable Research Station, Junagadh Agricultural University, Junagadh (India) situated at 21° 30′ 55.6956″ N latitude and 70° 27′ 23.1984″ E longitude. The experiment was carried out in the month of January 2019 and mean temperature and wind velocity were 26°C and 13 km h^{-1} respectively. Trizophos and delta methylene pesticides solution was used for spraying on okra crop for protecting the crop from attack of white fly. Prior to start the experiment subjects were acclimatized with experimental protocol and asked to take sufficient rest before start of the operation.

2.1 Selection of subjects for the spraying operation

Ten male subjects were randomly selected for the ergonomic evaluation of sprayers. The care was taken while selecting the subject; it should medically and physically fit to undergoing the trials. The subject was selected on the basis of his age. The age group of the subjects varied in the range of 25–40 years because in this range maximum strength level is attained (Gite and Singh, 1997).

2.2 Ergonomic evaluation

The ergonomic evaluation of battery operated, power operated and lever operated knapsack sprayer was conducted to work out energy expenditure rate, overall discomfort rating, musculo-skeletal problems and work load during the operation. Heart rate and oxygen consumption rate was calculated before and after the operation. For this measurement duration of activity was taken 30 min. The average of physiological parameters of all 10 subjects is given in Table 1.

Table 1 Physiological parameters of the subjects

Variable	Physiological parameters	
	Average	SD
Age, year	32	4.67
Height, cm	157.4	3.40
Weight, kg	57.8	3.40
BMI	23.3	1.00

2.2.1 Heart rate (beats min^{-1})

The fitness band was used for measurement of heart rate of all 10 subjects at rest and working condition (beats-min^{-1}). Before the work, subjects were taken rest pause then their resting heart rate was measured by fitness band. After 30 min of operation working heart rate was measured. Change in heart rate at rest and operating condition was calculated by the following formula (Kumar and Parihar, 2018).

$$\Delta \text{ HR (beat min}^{-1}) = \text{Avg. working heart rate} - \text{Avg. resting heart rate} \quad (1)$$

2.2.2 Oxygen consumption rate (lit min^{-1})

The oxygen consumption rate (VO_2) is the amount of oxygen consumed by the operator. The oxygen consumption rates of all 10 subjects were calculated at resting and operating condition. Oxygen consumption

was calculated by using heart rate of the operator by using following equation (Singh et al., 2008).

Oxygen Consumption Rate (lit min^{-1}) = 0.0114HR - 0.68 (2)

Where,

HR = Heart rate, beats min^{-1}

2.2.3 Energy expenditure rate (kJ min^{-1})

The energy expenditure rate (EER) of all 10 subjects while operating the sprayers was calculated by using heart rate of the operator. The energy expenditure rate indicates that the level of bodily stress in relation to heavy work and it can be used to assess the level of effort to work out necessary rest pauses. The energy expenditure rate (EER) was determined by using the following formula (Nag and Dutt, 1979). (Calorific value of oxygen as 20.93 kJ l^{-1})

EER (kJ min^{-1}) = OCR × 20.93 (3)

2.2.4 Rest pause during Work

During every strenuous work in field, adequate rest is required to have an optimum work output. Better performance results can be expected from both the operator only when proper attention is given for the work rest schedule for different operations. The rest time was measured from the cease of the operation till the heart rate of the subject reaches resting level. Murrel (1965) provided the following formula to estimate the total amount of rest required for any given work activity on the basis of its average energy cost.

$$\boldsymbol{R = \frac{T(K-S)}{K-1.5}} \quad (4)$$

Where,

R= Rest time required, min

T= Total working time, min

K= Average kcal per min of work

S= Average kcal per min adopted as standard.

The value 1.5 in the formulae was an approximation of resting level in kcal per min. Grandjean (1969) stated that most investigators agreed that the norm for energy consumption during heavy work should be 4 kcal min^{-1} but the spraying operation having work load light to moderate the accepted value was 2 kcal min^{-1}.

2.2.5 Work load

The classification of workload during the spraying period was done on the basis of average heart rate and average energy expenditure. Workload of activity was categorized as per the following classification of workload (Table 2) in different occupations proposed by Varghese et al., (1994).

Table 2 Classifications of workload

Physical work load	Physiological variables	
	Energy expenditure rate (kJ min^{-1})	Heart beats (beats min^{-1})
Very light	Up to 5.0	Up to 90
Light	5.0 – 7.5	91 – 105
Moderate	7.6 – 10.0	106 – 120
Heavy	10.0 – 12.5	121 – 135
Very Heavy	12.6 – 15.0	136 – 150
Extremely heavy	< 15.0	Above 151

Source: Varghese et al., (1994)

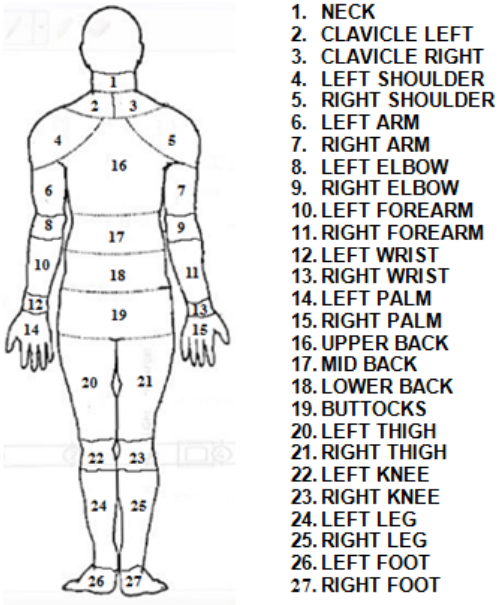

Figure 1 Body parts to evaluate musculo-skeletal problem (MSP)

2.2.6 Musculo-skeletal problem (MSP)

Musculo-skeletal problems were evaluated by asking the respondents as to where they felt pain in their body by operating all three sprayers. Figure 1 showed the body parts of the subjects.

2.2.7 Overall discomfort rate (ODR)

Overall discomfort rate (ODR) was measured on a 10-point visual analogue scale (0- no discomfort, 10- extreme discomfort) that is an adoption of a technique developed by Corlett and Bishop (1976). A scale of 100 cm length was made by having 0 to 10 digit marked on it equidistantly as shown in Figure 2. A movable pointer was provided to indicate the rating. At the end of each

trial, the subjects were asked to indicate their overall discomfort rating on the scale.

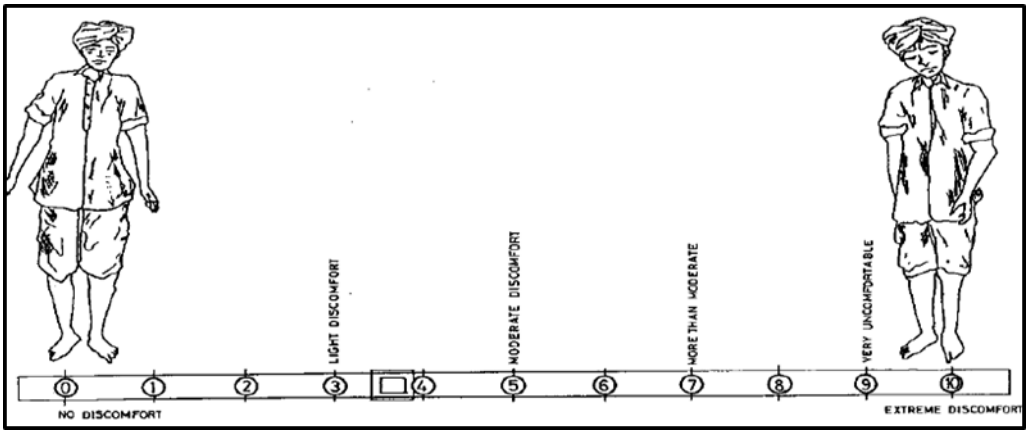

Figure 2 Visual analog discomfort (VAD) scale for assessment of overall discomfort rating (Corlett and Bishop, 1976)

2.3 Independent parameters for evaluation

Operators forward speed (V1, V2 & V3) and operating hours (T1, T2 & T3) these two parameters were considered for the statistical analysis.

(1) Forward speed: 1 km h^{-1} (V1), 1.5 km h^{-1} (V2) and 2 km h^{-1} (V3)

(2) Operating hours: 09.00 a.m. – 11.00 a.m. in Morning (T1),

12.00 p.m. – 15.00 p.m. in Afternoon (T2)

16.00 p.m. – 18.00 p.m. in Evening (T3)

The statistical analysis was carried out by using Factorial Complete Randomized Design (FCRD).

3 Results and discussion

3.1 Ergonomic evaluation

The results obtained during ergonomic evaluation of battery operated, power operated and lever operated knapsack sprayer is discussed below.

3.1.1 Effect of forward speed and working hours on heart rate of operator while spraying

The effect of forward speed and operating time duration on heart rate of operator is shown in Figure 3. It was observed that as the forward speed increased, the operator's heart rate increased during 12.00 to 15.00 hours (T2). The heart rate of the operator was found more as compare to morning hours (T1) and evening hours (T3) and it may be due to high temperature effect.

The average heart rate of the subject was 80.30 beats min^{-1} at rest condition. The average heart rates of the subjects were 97.44 beats min^{-1}, 102.66 beats min^{-1} and 111.67 beats min^{-1} during spraying operation by battery operated, power operated and lever operate knapsack sprayer respectively as shown in Figure 4. The reason for more heart rate for power and lever operated sprayer was the vibration created due to the engine in power sprayer and continuous operation of lever in lever operated sprayer.

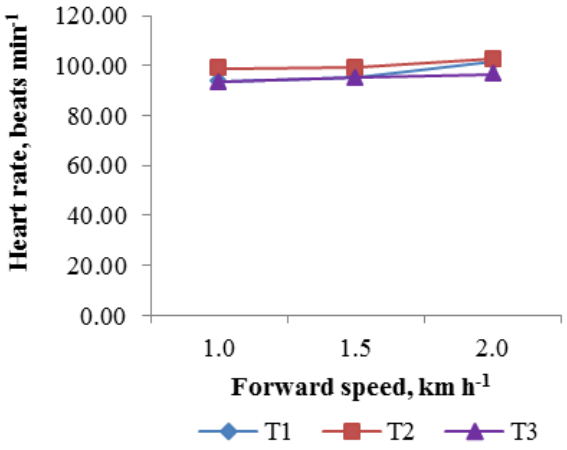

Figure 3 Effect of forward speed and operating hours on heart rate of operator

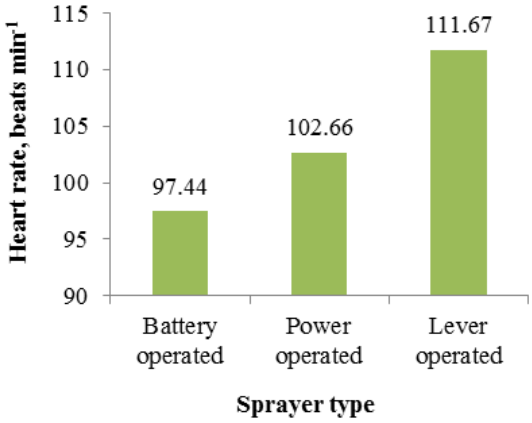

Figure 4 Variation in heart rate of operator for different types of sprayers

From the analysis of variance it was observed that forward speed of operator and time duration individually

showed highly significant effect on heart rate of operator for all three types of sprayers and the combination of both variables also showed highly significant effect and coefficient of variation was 1.176%, 1.393% and 1.221% for battery operated, power operated and lever operated knapsack sprayer respectively.

3.1.2 Effect of forward speed and operating hours on oxygen consumption rate of operator during spraying

The oxygen consumption rate was calculated by using heart rate of the operator. The effect of forward speed of operators operating hours on oxygen consumption rate of operator during spraying operation is shown in Figure 5. It was observed that as increased in forward speed of the operator, the oxygen consumption rate of the operator increased and the reason was more tiredness increase in operator. Also, as changed in operating hours morning to evening the oxygen consumption rate in the afternoon (T2) is more as compared to the morning and evening hours. Average oxygen consumption rate (VO2) of all subjects at resting condition was 0.24 lit min^{-1}.

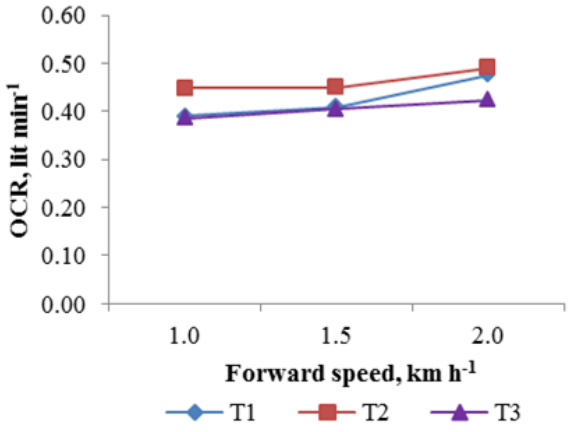

Figure 5 Effect of forward speed and operating hours on oxygen consumption rate of operator

It was observed that the oxygen consumption rate (VO2) of operator during spraying operation by battery operated, power operated and lever operated knapsack sprayer was 0.43 lit min^{-1}, 0.49 lit min^{-1} and 59 lit min^{-1} respectively. From Figure 6, it was found that oxygen consumption rate of operator was more in case of lever operated sprayer than battery operated and power operated sprayer. The increased oxygen consumption rate is due to the proportion of heart rate with oxygen consumption rate.

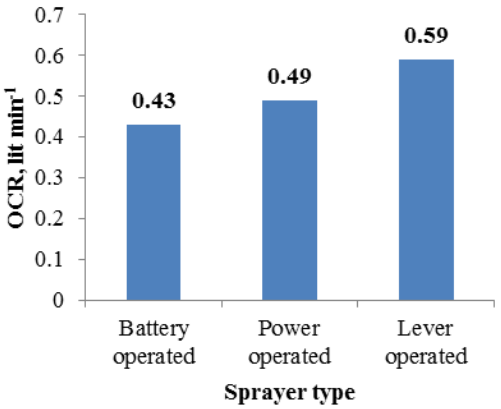

Figure 6 Variation in oxygen consumption rate of operator for different types of sprayers

From the analysis of variance, it was observed that forward speed of operator and operating hours individually showed highly significant effect on heart rate of operator for all three types of sprayer. The combination of both variables showed the significant effect for battery operated sprayer and highly significant effect on power operated and lever operated knapsack sprayer. The coefficient of variation is 3.192%, 3.469% and 2.751% for battery operated, power operated and lever operated knapsack sprayer respectively.

3.1.3 Effect of forward speed and working hours on energy expenditure rate of operator while spraying

The energy expenditure rate for all the subjects during spraying operation by using all three types of sprayers viz., battery operated, power operated and lever operated knapsack sprayer was worked out on the basis of mean heart rate during the spraying operation. The energy expenditure rate of operator during spraying operation by battery operated, power operated and lever operated sprayer was found to be 9.02 kJ min^{-1}, 10.26 kJ min^{-1} and 12.41 kJ min^{-1} respectively. The effect of forward speed of operators operating hours on energy expenditure rate of operator during spraying operation is shown in Figure 7. It was observed that an increase in oxygen consumption rate due to change in operating hours, the energy expenditure rate was also increased. From Figure 8, it was found that energy expenditure rate was more for lever operated knapsack sprayer. The continuous vibration of engine and hand lever in power knapsack sprayer and lever operated knapsack sprayer creates more fatigue in operator, due to that energy expenditure rate is more in case of both the sprayer.

Also, as changed in operating hours morning to evening the energy expenditure rate in the afternoon (T2) was more as compared to morning and evening hours.

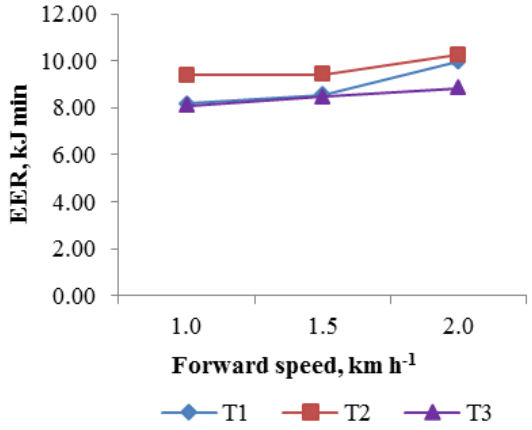

Figure 7 Effect of forward speed and operating duration on energy expenditure rate of operator

From the analysis of variance it was observed that forward speed of operator and operating hours individually showed highly significant effect on energy expenditure rate of operator for all three types of sprayer, and combination of both variables also showed highly significant effect for all types of sprayer. The coefficient of variation was 3.192%, 3.469% and 2.751% for battery operated, power operated and lever operated knapsack sprayer respectively.

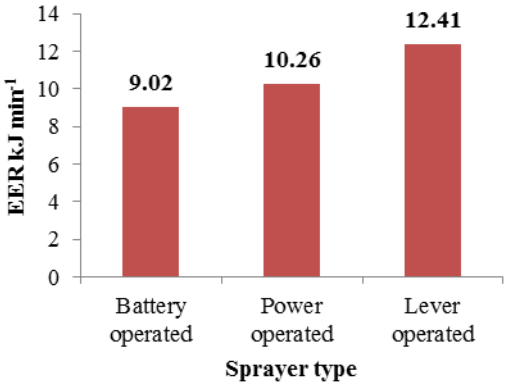

Figure 8 Variation in energy expenditure rate of operator for different types of sprayers

It was observed that the forward speed of operator 1.5 km h^{-1} (V1) with operating duration morning (T1) and evening hours (T3) gave better result of all physiological parameters with maintaining the work quality and effective field capacity with operators health. The average value of the physiological parameters of the all 10 subjects is given in Table 3.

Table 3 Physiological characteristics of participants

Sr. No.	Variables	Type of sprayer	Average	SD
1.	HR during operation, beats min^{-1}	Battery operated knapsack sprayer	97.44	3.27
		Power operated sprayer	102.66	3.37
		Lever operated knapsack sprayer	111.67	4.61
2.	OCR during operation, lit min^{-1}	Battery operated knapsack sprayer	0.43	0.04
		Power operated sprayer	0.49	0.04
		Lever operated knapsack sprayer	0.59	0.05
3.	EER during operation, kJ min^{-1}	Battery operated knapsack sprayer	9.02	0.78
		Power operated sprayer	10.26	0.81
		Lever operated knapsack sprayer	12.41	1.10

3.2 Rest pause

The rest pause for the spraying operation was worked out as explained in section 2.2.4. It was observed that, the actual rest time taken for spraying after 1h continues operation were 14.20 min, 28.48 min and 39.45 min respectively for battery operated, power operated, and lever operated knapsack sprayer and it was agreed with the computed value of rest pause.

3.3 Work load

The spraying activity was classified as light to moderate while using battery operated and power operated knapsack sprayer and moderate to heavy with lever operated knapsack sprayer. Farmers were comfortable while working with battery operated knapsack sprayer as they relive from back pain, shoulder pain, arm pain, elbow pain and fatigue developed created due to continuous lever operation and vibration of engine in power operated sprayer.

3.4 Musculo-skeletal problems (MSP)

Musculo-skeletal problems and posture were evaluated by asking the respondents as to where they felt pain in their body after spraying operation by all three sprayers such as battery operated, power operated and lever operated knapsack sprayer. The spraying operation by lever operated knapsack sprayer cause severe pain in right shoulder, right arm, right elbow, right wrist, right forearm and right palm, etc. because of continuous operation of lever. The power operated sprayer causes

back pain in the operator due to the continuous vibration and heavy load of the sprayer. In case of battery-operated knapsack sprayer, above problems was fully reduced and farmer could do continuous spraying for longer time.

3.5 Overall discomfort rating (ODR)

In lever operated knapsack sprayer musculo-skeletal problems are pronounced because of continuous movement of lever. More than moderate discomfort occurred in various parts of the body by using lever operated knapsack sprayer, moderate discomfort occurred in various body parts by using power operated sprayer and light discomfort occurred by using batter operated sprayer. The average observations of the musculo-skeletal problems and overall discomfort rating for all the subjects are given in Table 4.

Table 4 Responses on musculo-skeletal problems and overall discomfort rating (ODR)

S. No.	Machine	ODR	MSP
1.	Lever operated knapsack sprayer	5 - 7	More than moderate discomfort occurs in various body parts of operators. Severe pain occurs in right shoulder, right arm, right elbow, right wrist, right forearm and right palm, etc.
2.	Power operated knapsack sprayer	3 - 4	Light to moderate discomfort occurs in various body parts of the operator. Severe pain occurs in back and light pain occurs in right shoulder, right elbow and right wrist, etc.
3.	Battery operated knapsack sprayer	2 - 3	Light discomfort occurred in various body parts of the operator. Very light pain occurs in back, right shoulder, right elbow and right wrist, etc.

4 Conclusion

Ergonomic parameters like heart rate, oxygen consumption rate and energy expenditure rate increased with the increase of forward speed of operator and also more in afternoon hours (12.00 p.m. – 15.00 p.m.) than morning and evening hours. The forward speed of operator 1.5 km h^{-1} with morning and evening hours are suitable for spraying operation by using battery operated knapsack sprayer. Heart rate, oxygen consumption rate and energy expenditure rate were more in case of lever operated knapsack sprayer than power and battery operated knapsack sprayer. Average value of heart rate, oxygen consumption rate and energy expenditure rate for all the subject was 97.44 beats min^{-1}, 0.43 lit min^{-1} and 9.02 kJ min^{-1} respectively. The rest pause is required as 14.20 min for 1 h continuous spraying operation by using battery operated knapsack sprayer and light to moderate work load occurred on operator. Very Light discomfort was occurred by using batter operated knapsack sprayer. This battery-operated knapsack sprayer is acceptable to farmers for continuous spraying operation with minimum fatigue and body pain development.

References

Corlett, E. N. and R. P. Bishop. 1976. A technique for assessing postural discomfort. *Ergonomics*, 19(2): 175-182.

Gite, L.P. 1991. Ergonomics evaluation of a lever-operated knapsack sprayer. *Journal of Applied Ergonomics*, 22(4) : 241- 250.

Gite, L.P. 1993. Ergonomics in Indian agriculture – A review, Paper presented in the International workshop on Human and Draught Animal Powered Crop Protection held at Harare, Jan. 19-22.

Gite, L. P. and G. Singh. 1997. Ergonomics in agricultural and allied activity in India. CIAE Technical Bulletin No. CIAE/97/70, pp: 12-14.

Grandjean, E. 1969. Fitting the Task to Man - An Ergonomic Approach. Taylor and Francis, London, pp161.

Kumar, V. and N. S. Parihar. 2018. Ergonomic evaluation of manually operated single row manual vegetable transplanter. *Journal of Pharmacognosy and Phytochemistry*, 7(3): 683-685.

Murrell, K.H.F. 1965. Ergonomics - Man in his Working Environment. Chapman and Hall, London, pp: 339-348.

Nag, P. K. and P. Dutt. 1979. Effectives of some simple agricultural weeders with reference to physiological responses. *Journal of Human Ergonomics*, 8: 11-21.

Singh, S. P., L. P. Gite, J. Majumdar, and K. N. Agrawal. 2008. Aerobic capacity of Indian farm women using sun-maximal exercise technique on tread mill. *Agricultural Engineering International: The CIGR E-Journal*. Manuscript MES 08001. Vol. X.

Tamilselvi, P. and P. Anantha Krishnan. 2016. Ergonomic evaluation of conventional agricultural sprayers with respect to human performance. *Agric. Sci. Digest.*, 36: 179-184

Threadgill, E. and D. Smith. 1975. Effects of physical and meteorological parameters on the drift of controlled-size

droplets. *Transaction of ASAE*, 18(1): 51-56.

Varghese, M. A., P. N. Saha, N. Atreya. 1994. A rapid appraisal of occupational workload from a modified scale of perceived exertion. Ergonomics, 37(4): 485-491.

Yadav, R. and S. Pund. 2007. Development and ergonomic evaluation of manual weeder. *Agricultural Engineering International: The CIGR E-Journal*, Manuscript PM 07 022. Vol. IX.

Yadav, R., M. Patel, S. P. Shukla, and S. Pund. 2007. Ergonomic evaluation of manually operated six-row paddy transplanter. *International Agricultural Engineering Journal*, 16(3-4): 147-157.

Zilpilwar, S. R., S. R. Kalbande, and A. S. Ghadge. 2018. Development of solar cum hand operated hybrid knapsack sprayer for vegetable crops. *International Journal of Pure and Applied Biosciences*, 6(3): 748-756.