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Performance Comparison of Conventional Lever-Operated and Solar-Powered Knapsack Sprayers

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Abstract: *One of the most common techniques for applying pesticide is the use of lever-operated knapsack sprayer that is readily available and cost effective, tedious in operation. However, it cause pains and fatigue on the operator due to continuous manual agitation of the lever arm. To reduce this drudgery, a solar power-operated knapsack sprayer was designed and constructed. Its major components include pesticide tank, solar panel, nozzles, battery, lance DC pump and a voltage switch. The objective of this study was to compare the performances of the conventional knapsack sprayer and the developed solar powered sprayer both in the field and in the laboratory with the hope of finding a suitable sprayer that would reduce the drudgery encountered by the famer. Parameters determined include the spray swath width, droplet size, droplet density, field capacity and application rate. Physiological parameters of the operator and some ergonomic parameters of selected spraying systems were also compared to ascertain the operator's comfort. Results obtained indicated that the lever-operated sprayer has a maximum of 80% efficiency against the 98% of the solar-powered. Similarly, the physiological cost of spraying was higher for lever-operated knapsack sprayer. Heartbeat rate during the sprayer operation ranges from 83 to 87 beats per minute for the lever operated sprayer. The operating energy required for operating sprayers also varied between the 30.27 kJ/min (sprayers: lever-operated) and 4.73 kJ/min (solar-powered) which is clear indicative that the lever-operated sprayer could not be operated for longer duration without adequate rest.*

Keywords: *Knapsack, Evaluation, Efficiency, Solar-Powered, Application, Parameters*

INTRODUCTION

Pesticides are substances or a mixture of substances intended to prevent, destroy, control pests and unwanted species of plants that causes harm or interfere with the production, processing, storage, transport and/or marketing of food and agricultural commodities (FAO, 2007). Its application refers to the practical way in which the pesticides are delivered to the biological targets (Bateman, 2003). One of the most common forms of pesticide application methods in agricultural production is the use of sprayers such as knapsack sprayer by mounting the sprayer tank on the back of the operator. These sprayers convert the pesticide formula, often containing a mixture of water and chemical into droplets, into tiny almost-invisible particles. The conventional lever operated knapsack sprayers are the most common sprayers used to achieve this in Nigeria.

However, these sprayers require continuous pumping via manual lever to actuate and atomize the liquid on the target thereby causing a lot of fatigue and pain on the operator as well as backache due to the weight of the mounted spray tank (Govinda *et al*., 2017). In addition, the lever operated sprayer pump cannot be used continuously for more than 5 – 6 hours as the operator often gets tired (Bhanagare, 2015). Similarly, the sprayer does not provide constant pressure which guaranty optimum pesticides application quality. Such pressure fluctuation varies the droplets spectrum, the spray pattern quality, uniformity of liquid distribution and thus pose potential risk of drift (Robson, 2014 and Nuyttens *et al*., 2009). To improve spraying performance in order to obtain better spraying efficiency and eliminate the hardships associated with the conventional knapsack sprayers, the need to device an alternative user-friendly spraying equipment becomes paramount. To address these problems and reduce the drudgery and stress due to manual agitation of the lever arm, a solar power-operated knapsack sprayer was designed and a prototype produced at the Crop Protection Unit of the Department of Agricultural and Bio-resources Engineering, Ahmadu Bello University, Zaria. Its major components include pesticide tank, solar panel, nozzles, battery, lance, DC pump. The objective of this study is, therefore, to compare the performance of the conventional lever-operated and the developed solar-powered knapsack sprayers both in the field and the laboratory with the aim of guiding the farmer on the suitability of using them in order to achieve the desired results with minimum drudgery and less cost.

MATERIALS AND METHODS

A 20-liter conventional lever-operated knapsack sprayer (Fig. 1) and a 16-liter solar-powered knapsack sprayer (Fig. 2) developed at the Department of Agricultural and Bio-Resources Engineering of the Ahmadu Bello University, Zaria-Nigeria were the basic materials selected to be used for the study. In addition to the components of the conventional lever-operated knapsack sprayer, the developed solar-powered knapsack sprayer consists of solar panel, rechargeable battery, DC pump, solar panel frame, battery and pump casing, and solar charged controller.

Fig. 1 Conventional Lever Operated Knapsack Sprayer

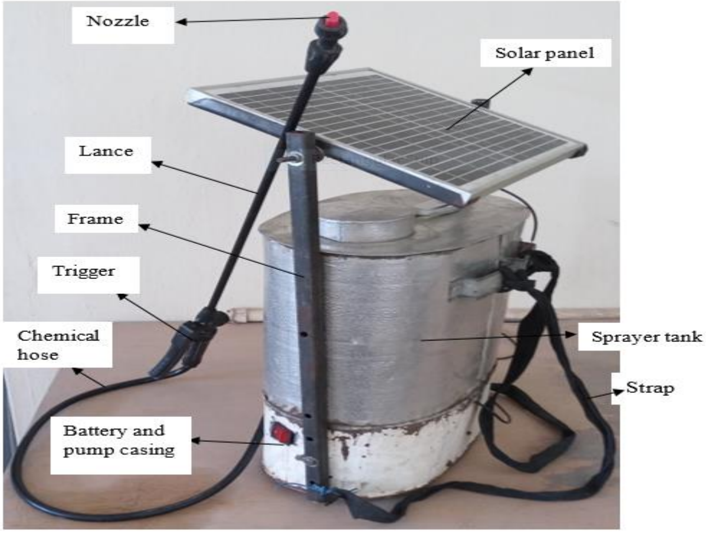

Fig. 2 Pictorial representation of the developed solar powered sprayer

The instruments used in the performance evaluation of the sprayers were; 100 ml measuring cylinder, stopwatch, pattern-meter and pressure gauge, 5 m measuring tape, 20-liters plastic bucket, peg, Nozzles (Fan and Hollow Cone Nozzle) and Pumps (Citron and Toyota). The performance of both sprayers were evaluated in the laboratory and the field. The study conducted at the Crop Protection laboratory of the Department of Agricultural and Bio-Resources Engineering, Ahmadu Bello University, Zaria. The parameters determined include: Flow rate, Spray volume distribution pattern, Droplet sizes, Swath width, and Droplet density. The performance indicators for the field evaluation were: Theoretical field capacity, Effective field capacity C_e, application rate A, and efficiency. The effective field capacity is the measure of actual area covered during spraying operation at a specific time. This was determined as follows (Bhanagare, 2015).

$$C_e = \frac{A}{T} \tag{1}$$

where,
C_e = Effective field capacity ha/hr
A = Area covered ha
T= Spraying time h

The conventional lever-operated and solar powered operated knapsack sprayers were put in proper condition before conducting the tests. The operator was also trained on the operation of the sprayers prior to the experiment. The operator reported at the work site at 6.00 am and have a rest for at least 30 min before the commencement of the trial experiments having trekked from his village covering a distance of about 1½km to the experimental site on each day of the experiment. The experimental requirements were clearly stated to the operator for proper cooperation while the test lasts. Ergonomic performance evaluation of the sprayers was conducted in the morning hours of 7.00 – 9.30 am. A healthy male operator of about 30 years (based on age and medical fitness) was used for the study. The choice of the operator based on the recommendations of Shubham *et al.* (2018) and Gite (1996) that recommend healthy farm laborer in the age group of 25 to 35 years. RNAM (1983) test code was used to determine the speed of travel (km/h) of the operator of known distance (20 m). Parameters evaluated include; heartbeat rate, average oxygen consumption and rate of energy expenditure. An average forward speed of 1.2 was used in conducting the study as recommended by Awulu and Sohotshan (2012); Shubham *et al.* (2018) and Gite (1996). The heartbeat rate was measured and recorded using polar heart rate monitor for the entire work period. Each trial started with taking 5 min data for physiological responses of the operator while resting on a stool under shade. The operator was then asked to operate the sprayer (already started by another person) for duration of 15 minutes and same procedure was replicated thrice.

2.1 Description of the Developed Solar-Powered Knapsack Sprayer

Fig. 2 presents the components of the developed solar-powered knapsack sprayer. A 16-liter tank was, therefore considered adequate since the study was focused small-holder farmers. Light aluminum sheet for roofing was used because of its light weight and resistance to corrosion as well as ensure operators comfort and extend the life span of the sprayer. The solar panel is the main power generating system. It was mounted slightly above the head of the operator to be able to tap energy from the sun and convert it into electricity via a battery that powered the pump and other useful components of the sprayer. The specifications of the panel (size – 34.5 × 28.5 cm; peak power – 10W; voltage – 18V and weight – 1kg) were carefully selected to provide the needed power that would conveniently power the sprayer. Its weight is also negligible such that it does not constitute a burden to the operator. A mild steel frame was constructed to serve as a housing for the solar panel. Its purpose was to provide a shield that would protect the panel from possible damage while in operation. A 12 V DC motor pump was used to lift the pesticide from the tank and deliver it to the spray nozzle. DC motor of this capacity was selected because of its versatility in applications and its ability to automatically change the armature current to meet the load requirement. The solar powered-knapsack sprayer was also provided with a 12V (7Ah) battery that could be used as an alternative source of power during cloudy atmosphere. This was to ensure constant supply of power to enable the farmer have access to use the sprayer when needed. Different types of nozzles are used to spray depending upon the farmer's requirement. For this study, two types of nozzles were used: the hollow cone and fan nozzles. Hollow cone nozzles enable the pesticide to be emitted in the form of a narrow conical sheet which then breaks up into small drops while the fan nozzle forms narrow elliptical spray pattern. The lance tube is an extension rod made from fiber material long enough to enable the spray reach the target appropriately. It was made from mild steel in order to have the strength needed to withstand the rigor involved. Finally, an electrical switch that would aid the actuation and disconnection of flow of current to the pump and entire sprayer system was provided.

2.2 Principle of Operation of the Developed Solar-Powered Knapsack Sprayer

The solar panel with specifications of 18 V, 10 W was mounted slightly above the head of the operator to charge the battery connected to it. The solar panel made of photovoltaic cells converts the solar energy into electrical energy. The current generated by the solar cells was supplied to charge the battery and the battery was connected to the DC Pump. The DC pump produced high speed rotary motion which resulted in disintegration of the spray fluid through the spray nozzle at the rare end of the lance into fine droplets. The spray was achieved through direct discharge with lance to the target. Also, a fully charged battery could be maintained in the sprayer while the spraying operation is achieved directly by energy delivered solely by the solar panel. The motor had two openings; the inlet and outlet. The motor developed the suction and lift the liquid chemical from the tank, via connecting pipe and finally to the nozzles. The pesticides through nozzle, generated varying spray patterns. The discharged liquid through the nozzle can be controlled by the speed variable switch provided at the spraying unit. In this way liquid chemical was sprayed on the appropriate target area.

2.3 Physiological Parameters of the Operator

The conventional lever-operated knapsack sprayer and solar powered operated knapsack sprayer were put in proper condition before conducting the tests. The operator was also trained on the operation of the sprayers prior to the experiment. The operator was asked to report at the work site at 6.00 am and have a rest for at least 30 min before the commencement of the trial experiments having trekked from his village covering a distance of about 1½km to the experimental site on each day of the experiment. The experimental requirements were clearly stated to the operator for proper cooperation while the test lasts.

Ergonomic performance evaluation of the sprayers was conducted in the morning hours of 7.00 – 9.30 am. A healthy male operator of about 30 years (based on age and medical fitness) were used for the study. The choice of the operator based on the recommendations of Gite (1991) that the maximum expected strength of a farm laborer was determined in the age group of 25 to 35 years. RNAM (1983) test code was used to determine the speed of travel (km/h) of the operator of known distance (20 m). Parameters evaluated include; heartbeat rate, average oxygen consumption and rate of energy expenditure. The heartbeat rate was measured and recorded using polar heart rate monitor for the entire work period. Each trial started with taking 5 min data for physiological responses of the operator while resting on a stool under shade. The operator was then asked to operate the sprayer (already started by another person) for a duration of 15 minutes and same procedure was replicated thrice.

Table-1 Simulation parameters

Parameter	Symbol	Value	Unit
Moment inertia of robot	J	5	Kg m^2
Robot mass	M	12	kg
Location of centre of gravity of robot	d	0.05	m
Radius of wheel	r	0.075	m
Distance between wheel	L	0.2	m
The torque constant	kt	0.035	Nm/Amp
The back emf constant	kb	0.035	V/rad/s
Inductance of the armature winding	La	0.0	H
Resistance of the armature winding	Ra	8	Ohm
The gear ratio	N	2	

For each wheel the values 220 and 10 were obtained from the iterations carried out for the proportional K_p and integral K_i components in the PID controller. 0 was used for the derivative K_d component.

RESULTS AND DISCUSSION

The performances of the field trials of the lever-operated and solar power-operated sprayer were carried out and the results obtained were compared (Tables 2 and 3) using cone and fan nozzles. It was observed that the width (swath width) of spraying affects effective field capacity of sprayer. The average observed width was 1.58 and 1.08 m, respectively for fan and hollow cone nozzles when solar powered sprayer was used. This was against 1.5 and 1.06 m, respectively for the conventional lever operated sprayer. It was generally observed that the swath width obtained for fan nozzles was more than those of cone nozzle for both sprayers, possibly because of the design of the two nozzles. This assertion agreed with Taylor *et al.* (2004) who observed that the spray features of sprayer nozzles are significant criteria in the application of chemicals because of their ultimate result on the efficiency of the spraying process. Droplet size thus influences the formation of the spray deposits and the drift capability of the droplets. The theoretical and effective field capacities of the solar power operated sprayer was found to be relatively higher than those of the conventional lever operated sprayer when hollow cone and fan nozzles were used. Similarly, the field efficiency of the solar sprayer was higher than the conventional lever operated knapsacks sprayer. In the same vein, Mittal *et al.* (1996) reported that among all the farm operations, power spraying was the most detrimental because of vibrations transmission to human body parts. It results in early fatigue and reduced work output of the workers.

Table-2 Performance Evaluation of the Conventional Lever Operated Knapsacks Sprayer

S/N	Nozzle Types	Droplet sizes (µm)	Droplet Density (g/ml)	Swath Width (m)	Flow Rate (mL/min)	Application Rate (L/ha)	Effective Field Capacity (ha/hr.)	Theoretical Field Capacity (ha/hr.)	Field Efficiency (%)
1	Hollow Cone	250	119	1.06	668	262.9	0.36	0.45	80.00
2	Fan	333	81	1.5	1837	212	0.30	0.38	78.95

Table-3 Performance Evaluation of Solar Power-Operated Knapsacks Sprayer

S/N	Nozzle Types	Droplet sizes (µm)	Droplet Density	Swath Width (m)	Flow Rate (mL/min)	Application Rate (L/ha)	Effective Field Capacity (ha/hr.)	Theoretical Field Capacity (ha/hr)	Field Efficiency (%)
1	Hollow Cone	206	113.06	1.08	430.00	147.41	0.39	0.40	98.05
2	Fan	246	105.67	1.58	528.33	263.67	0.36	0.38	98.00

These efficiencies were also observed to be dependent upon the swath width, flow rate, application rate, speed and skill of operator. The field efficiency of the solar powered sprayer was found to be uniform when both hollow cone and fan nozzles were used (approximately 98 %). These findings were in perfect agreement with the observations of Awulu and Sohotshan (2012), Pandurang *et al.* (2015) that lever operation induces fatigue to workers along with greater variation in spray pressure results inconsistency of application which adversely affect pest control. The average application rate of the Solar Charge Battery-Operated Knapsack Sprayer was 147.41 and 263.67 l/ha for cone and fan nozzles, respectively. These values were lower than what was obtained when lever operated sprayer was used indicating that solar power-operated sprayer was more economical to be used. The solar power sprayer is, therefore, an improved spraying technique could be superior to the sustainable use of the crop protection inventions as earlier observed by Foqué and Nuyttens (2011). This has been widely affirmed by Magar *et al.,* (2017) who mentioned that by eliminating the use of lever operation during spraying, the method of spraying becomes more eco-friendly and reduces fatigue for user. Robson *et al.,* (2014) also alluded to the fact that the solar powered sprayer "is a clean type, does not emit carbon dioxide, has flexibility of use and is of simple operation and maintenance. With the development of solar powered battery knapsack sprayer, the use of some expensive inputs and frequent charging of battery from expensive electricity supply is eliminated. The operator's physiological data were taken as given in Table 3.

Table-4 Physiological parameters of the operator

Operator's Variables	Physiological Data
Height (m)	1.66
Weight (kg)	64
Age (years)	30
Resting Heartbeat Rate (Beat/min)	68
Resting Blood Pressure (mm of Hg)	110/80

The factors causing the physical fatigue while operating the sprayers were weight, operating force and energy. Hence the need for refinement of sprayers based on limitations and capabilities of the lever operated knapsack sprayer was felt. The comparison of ergonomic parameters of the conventional lever operated knapsack sprayers with solar powered operated knapsack sprayers in the field and the observations are given in Table 5.

Table-5 Comparison of Ergonomic Parameters of Selected Spraying Systems

S/N	Parameters	Type of Sprayer	
		Lever-Operated	Solar-Power Operated
1	Mean heart rate (Beats/min)	85	71
2	Mean oxygen consumption (l/min)	1.68	1.23
3	Mean Energy expenditure (kJ/min)	30.27	25.54
4	Oxygen consumption rate	50.25	43.12
5	Overall Discomfort Rate (ODR)	5.37	4.10

The physiological parameter (heart rate) along with postural parameter of Overall Discomfort (ODS) were observed for all the experiments (Table 5). The mean heart rate was lowest for the solar sprayer compared to the conventional lever operated sprayer indicating lower physiological demand and discomfort to the body parts. Similarly, the overall discomfort for solar power – operated sprayer was lower than the manual sprayer. Lower energy demand and postural comfort was because of non-requirement of "rocking the pump lever" as it was powered with battery. Thus, in solar sprayer with lower heartbeat rate and postural discomfort, the output obtained was more compared to the other two sprayers. Comparing the two sprayers, the physiological cost of spraying was higher for lever-operated knapsack sprayer. This might be due to the ergonomic refinements carried out. Heartbeat rate during the sprayer operation ranges from 83 to 87 beats per minute for the lever operated sprayer. It is observed that with increase in pressure, the heartbeat rate was also increased. Lesser increase of heart beat rate was observed while operating the solar powered sprayer possibly because less pressure was experienced with the elimination of the continuous pumping. Similarly, oxygen consumption was observed to be higher for the lever-operated sprayer since the heartbeat rate was higher. The operating energy required for operating sprayers also varied. For the lever operated sprayer, the mean energy expenditure was 30.27 kJ/min. This value was 4.73 kJ/min higher than that what was obtained from the solar-powered sprayer which is clear indicative of the fact that these sprayers could not be operated for longer duration without adequate rest. This indicates that at high pressure rate, the energy expenditure tends to increase during the operation as suggested by Awulu and Sohotshan (2012) and Gite (1996). The results obtained also agreed with Smil (1994) who observed that while performing exercise with faster movement, human muscles must contract more rapidly, consuming proportionately more energy.

From the mean values of overall discomfort rate, discomfort experienced by the operator was lesser for solar power-operated knapsack sprayer when compared with other sprayers. Less body discomfort was experienced by solar power-operated sprayer possibly because the continuous actuation of the lever was eliminated. The majority of discomfort experienced by the operator was in clavicle right shoulder, left shoulder and lower back for all the subject since the sprayer was being carried on the back of the operator for all the types of the spraying activity. The discomfort experienced by the operator was mainly due to the alternate up and down, push and pull action associated with the operation of the lever-operated sprayer coupled along with the additional effort required to spray fields. Drudgery caused due to bad posture is reflected in terms of postural discomfort experienced by the worker. Ghugare *et al.* (1991) and Shubham *et al.* (2018) also discovered that maximum discomfort in the body parts was experienced in the lever-operated knapsack sprayer in the left clavicle region, followed by lower back, neck, left thigh and right clavicle. The above results confirmed that solar-powered sprayer performed better than the lever-operated sprayer.

CONTRIBUTION TO KNOWLEDGE

This study has established the use of solar-operated knapsack sprayer has brought about reduced drudgery that was caused by the pain and fatigue suffered by the operator due to continuous manual agitation of the lever arm while using the conventional lever-operated knapsack sprayer. It has also reduced the physiological discomfort of the operator when compared to the use of the lever-operated knapsack sprayer.

CONCLUSION

The performance evaluation of the conventional lever operated and solar-operated knapsack sprayers was conducted to ascertain their spraying efficacy and their performance was compared. The performance indices were droplet size, droplet density, swath width, application rate, flow rate, spray volume distribution and field efficiency using hollow cone and fan nozzles. The lever-operated sprayer had a maximum efficiency of about 80% against 98% of the solar-powered sprayer. The physiological parameter (heart rate) along with postural parameter of Overall Discomfort (ODS) were also investigated. Mean energy expenditure of 30.27 kJ/min was noted while operating the lever-operated sprayer as against 4.73 kJ/min obtained from the solar-powered sprayer. This results in high physiological cost of spraying with the lever-operated knapsack sprayer. Similarly, more discomfort in the body parts was observed while using the lever-operated knapsack sprayer. The solar-powered sprayer was, therefore, found to be more convenient than the conventional lever-operated sprayer since it has the tendency of reducing pains and fatigue on the operator.

CONFLICT OF INTEREST

The authors declare no competing interest.

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