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Development and Performance Evaluation of a Solar Powered Knapsack Sprayer

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Abstract

One of the most common technique for applying pesticides is the use of knapsack sprayer. A lever-operated knapsack sprayer is readily available and inexpensive, but it is time-consuming to use. Because of the constant manual agitation of the lever arm, which actuates and pumps the pesticides through the reciprocation of the lever arm, the operator frequently suffers from pains and fatigue. To reduce the drudgery due to manual agitation of the lever arm, solar power-operated knapsack sprayer was designed and constructed. The components of the developed sprayer are the photovoltaic panel, lead battery, battery case, and battery-operated pump in addition to the components of the conventional lever-operated sprayer except for the sprayer handle that was eliminated. The performance evaluation of the developed solar - powered sprayer was carried out in both the laboratory and the field to examine the spray flow rate, spray volume distribution pattern, field capacity, and application rate. Results obtained show a uniform spray distribution of 20.66 % coefficient of variation. Similarly, 557 ml/min, 0.35 ha/hr and 380.40 l/ha were obtained for spray flow rate, field capacity and application rate, respectively. Results obtained also show that the developed solar-powered sprayer has greater field capacity than conventional lever-operated sprayer as its operation has reduced the drudgery involved in pesticide application, saves operators time as well as providing comfort for the operator.

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Introduction

Pesticides are substances or a mixture of substances intended for preventing, destroying, controlling 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 formulation, 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, the sprayer require continuous pumping via a 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, conventional lever - operated knapsack sprayers do 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 poses a potential risk of drift (Robson, 2014 and Nuyttens *et al.*, 2009). To improve spraying performance to obtain better spraying efficiency and eliminate the hardships associated with the conventional knapsack sprayers, the need to device alternative user-friendly spraying equipment becomes paramount. The objective of this study is, therefore, to provide a mechanism that would reduce, to the barest minimum, the drudgery and stress involved during pesticide application while using the conventional lever-operated knapsack sprayer. A knapsack sprayer that uses solar charged battery as its power source and suitable for pesticide application has thus been developed.

Materials and Methods

Materials selection

The developed solar - powered knapsack (Figure 1) sprayer consists of pesticide tank, solar panel, rechargeable battery, DC pump, nozzle, lance, solar panel frame, battery and pump casing, and solar - charged controller:

Pesticide tank - The pesticide tank was constructed with a light aluminum roofing sheet and has the capacity of 16 liters. This capacity was considered because a majority of farm holdings in Nigeria are less than 2.5 ha (Akinyele, 2009). **Solar panel** – It is the main power generating system for the sprayer. It was mounted on the frame and positioned slightly above the head of the operator. It has specifications of 34. × 28.5 cm in size, 10 W peak power, and 18V.

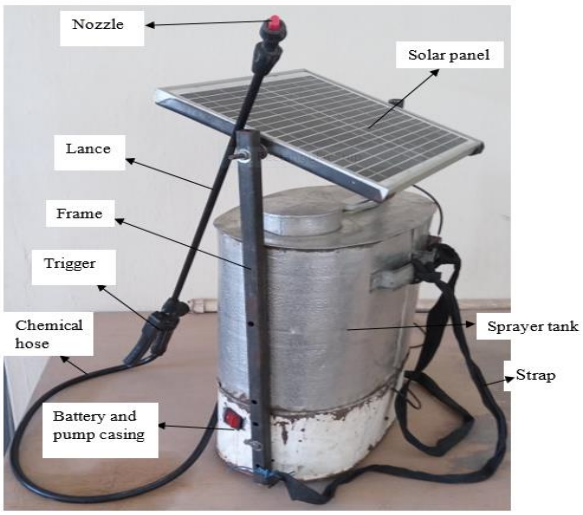

Figure 1: Pictorial representation of the developed solar powered sprayer

Pump - A 12V DC motor pump was used for lifting the pesticide from the tank and delivering it to the spray nozzle. **Battery** - The solar - powered variable voltage knapsack sprayer was provided with a 12 V (7Ah) battery that could be used as an alternative source of power during a cloudy atmosphere. **Spray nozzle** - Hollow cone and Fan nozzles were used in the study. **Lance tube** - This is an extension rod made from fiber material long enough to enable the spray reach the target appropriately. It was made from mild steel to have the strength needed to withstand the rigour involved. **Solar panel frame** - A mild steel frame was constructed to serve as housing for the solar panel. Its purpose was to provide a shield that would protect the panel from possible damage while in operation. **Battery-pump casing** - The battery and pump casing were placed at the bottom of the tank. It was made from mild steel such that it would be strong enough to withstand the weight of the sprayer. **On/off Switch** - The electrical switch aided the actuation and disconnection of the flow of current to the pump and entire sprayer system.

Principle of operation of the developed solar powered knapsack sprayer

The solar panel provides power to charge the battery. It was made of photovoltaic cells that convert solar energy into electrical energy. Current generated by the solar cells was supplied to charge the battery which in turn actuates the DC Pump. The DC pump produced high - speed rotary motion which disintegrated the spray fluid through the spray nozzle at the rare end of the lance into fine droplets. Alternatively, a fully charged battery could be maintained while the spraying operation is achieved directly by energy delivered solely by the solar panel. Pesticides from the tank would be lifted through the action of the pump and transmitted in varying spray patterns through the pipe/lance to the nozzle before reaching the target. A control valve was used to vary the flow rate as required while the spray was achieved. In this way, liquid pesticide/chemical was sprayed on the appropriate target area.

Design considerations

Determination of Energy requirements - The energy requirement by the solar panel was determined according to Aju-Adonsi *et al*. (2016) using equations 1, 2 and 3.

$$E = P_m \times h \quad (1)$$

$$P_m = V_m \times I_m \quad (2)$$

$$E_t = E \times 1.3 \quad (3)$$

where:

E = energy requirement (Wh)

P_m = power of the electric pump (W)

h = maximum time of spraying (7 hours)

V_m = voltage of the electric pump (12 v)

I_m = current of the electric pump (A)

E_t = energy requirement needed to be supplied by the solar panel (Wh)

Therefore, the solar energy requirement needed to be supplied for the operation of the system was 60.7 Wh.

Sizing of the solar panel - The size of the solar module needed for the spraying operation was estimated according to Esan and Egbune (2017) using the following equations.

$$Number\ PV\ needed = \frac{Total\ Watt{-}hour\ of\ PV\ panel\ capacity}{Watt{-}hour\ of\ the\ available\ PV} \quad (4)$$

$$Total\ Watt - hour\ of\ PV\ panel\ capacity = \frac{E_t}{PGF} \quad (5)$$

$$PGF = Solar\ Irradiation \times Total\ correction\ factor\ of\ the\ solar\ panel \quad (6)$$

where:

PGF = Panel generation factor

The average solar irradiation of Zaria, Kaduna State was given as 5.307 kWh/day (Abdulsalam *et al.*, 2012). Similarly, the total correction factor of 0.69 was estimated (Esan and Egbune, 2017). Therefore, the panel generation factor was computed as 3.662.

The total watt-hour of PV panel capacity was computed as 16.58 Wh. Considering the available solar module of 70 Wh (i.e. 10 W × 7 h) capacity, the The total battery capacity requirement (Bc) was determined from equation 7 (Rajesh *et al*., 2016),

$$B_c = \frac{E}{(DOD \times N_c)} \quad (7)$$

The total battery capacity requirement (Bc) was computed as 78.5 Wh. The total battery capacity of 12V and 7 Ah was sufficient for the design.

number of solar modules needed (from Equation 4) was determined as 0.229. Therefore, the solar module of 10W, 18V satisfies the design.

Sizing of the battery

The choice of batteries was done considering the following features:

i. Depth of discharge of rhe battery (DOD) is 0.70

ii. Battery loss of (N_c) 0.85

Similarly, the charging time of the battery was determined as:

$$T = \frac{Battery\ rating\ (7\ Ah)}{total\ current\ consumed\ by\ the\ panel\ (0.556\ A)} \quad (8)$$

Therefore, total time of charging was computed as 12 hours.

Performance Evaluation

Performance evaluation of the developed sprayer was conducted in the laboratory and the field to assess the effects of sources of power, pump types and nozzles types on the spray flow rate, spray volume distribution pattern, swath width, droplet size, field capacity and application rate.

Spray Flow - Spray flow rate was measured using a measuring cylinder to determine the discharge of the spray droplets in 60 seconds at a constant height of 45 cm and 7kPa (30 psi) in the following (Bhanagare, 2015)

Spray volume distribution pattern - The spray volume distribution pattern was determined using patternator. Spraying nozzle was suspended above the patternator, where the discharge was collected and recorded

Droplet size - The droplet size was determined at the laboratory using standard methods. This was to ascertain the ranges of droplet sizes.

Swath width - The swath width is the horizontal distance covered by the spray droplet in the patternator. This was determined by measuring the total distance covered by spray on the groove of the patternator.

Effective field capacity - The Effective field capacity is the measure of the actual area covered during spraying operation at a specific time. This was determined as follows (Bhanagare, 2015).

$$C_e = \frac{A}{T} \quad (9)$$

where:

C_e = Effective field capacity, ha/hr

A = Area covered, ha

T= Spraying time, h

Application rate - the application rate was determined as follows (Ashish *et al*., 2014)

$$Application\ rate\ \left({}^{l}/_{ha}\right) = \frac{Volume\ rate({}^{l}/_{hr})}{Area\ rate\ (\frac{ha}{hr})} \quad (10)$$

The performance evaluation was conducted considering the independent variables; sources of power (solar panel only and solar – battery sources), pump types (citron and Toyota pumps) and nozzle types (hollow cone and fan nozzles). The result was subjected to analysis of variance (ANOVA). Statistical analysis system software (SAS) was employed for the analysis.

Results and Discussion

The results of the performance evaluation of the developed solar - powered knapsack sprayer were presented in the subsequent headings.

Laboratory Evaluation

The result of the laboratory performance evaluation of the solar - powered knapsack sprayer is presented below. The effect of sources of power, nozzle types and pump types on performance indicators were determined.

Spray Flow rate – Results obtained shows the effect of sources of power and nozzle types being highly significant on the spray flow rate while the pump type was not significant at 5 % probability level as presented in Table 1. The first and second levels of interaction effects were highly significant on the spray flow rate. The result of the further analysis using the Duncan Multiple Range Test (DMRT) indicated that the solar panel – battery source recorded the highest mean spray flow rate of 557.42 mL/min followed by a hollow cone nozzle of 529.58 mL/min. While the solar panel only and fan nozzle recorded the least spray flow rate of 440.42 and 412.58 mL/min, respectively. The flow rate determined was significantly less than the mean flow rate recorded by the convectional knapsack sprayer of 0.023 L/s (1380 mL/m), Yallappa *et al*. (2016). This indicated that the developed solar-powered sprayer is economical as its flow rate reduces wastages of pesticides.

Table 1: Effect of sources of power, nozzle types and pump types on flowrate

Treatments	Mean Flowrate (mL/min)
Sources of Power S	
Solar only	440.42b
Solar and battery	529.58a
SE±	7.937
Nozzle Types N	
Fan	412.58b
Hollow Cone	557.42a
SE±	7.937
Pump Types P	
Citron	483.58
Toyota	486.42
SE±	7.937
Interaction	
S*N	**
S*P	**
N*P	**
S*N*P	**

Mean followed by same letter(s) in the same column are not significantly different at *P=0.05* using DMRT. **= Significant at ($P \leq 0.01$).

Spray Volume Distribution pattern - The effect of sources of power, pump types and nozzles types was assessed using the coefficient of variance (CV) as presented in Figures 2 and 3. Higher to low percent CV was adopted as disperse to uniform spray distribution pattern. The solar panel-battery power and citron pump with fan nozzle produced a more uniform spray distribution pattern as it recorded a lesser coefficient of variation (CV) of 20.66 % compared with CV of 39.08 % recorded for solar-battery power and Toyota pump with fan nozzle. However, the result was lower than that recorded by the conventional lever - operated knapsack spray.

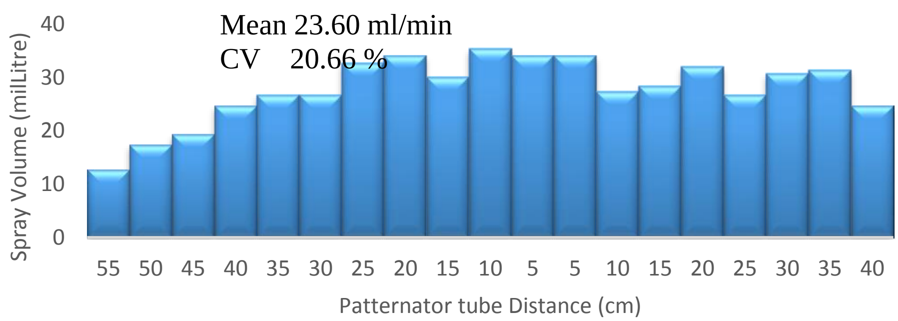

Figure 2: Solar-battery power, Citron pump and Fan nozzle on spray volume distribution

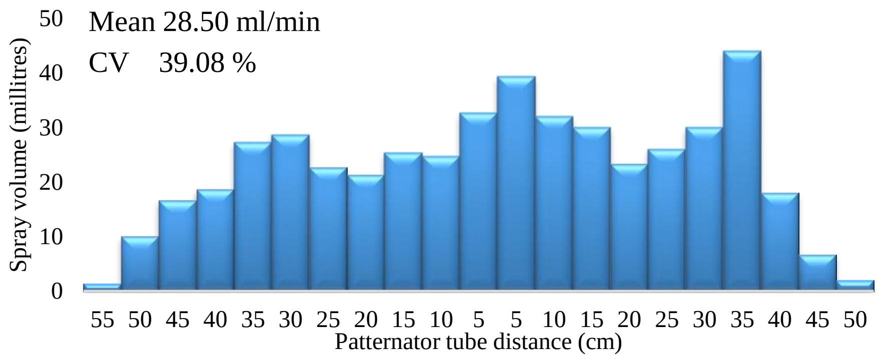

Figure 3: Solar-battery power, Toyota pump and fan nozzle on spray volume distribution

Swath width

The result of the analysis of variance of the effect of the sources of power, pump types and nozzle types on the spray swath width is presented in Table 2. The result shows that the effect of sources of power, pump types and nozzle types were highly significant on the spray swath width at 5 % probability level. The first and second levels interaction effects of sources of power, pump types and nozzle types were highly significant on the spray swath width.

The result of further analysis using the Duncan Multiple Range Test (DMRT) to assess the effect of the sources of power, pump types and nozzle types on the spray swath width indicated that combine solar and battery, fan nozzle and Toyota pump recorded the highest mean swath width of 0.86 m, 0.796 m and 0.783 m respectively. Higher swath width recorded by the solar and battery may be attributed to a higher voltage in position by the combined solar and battery. Likewise, the fan nozzle produced a spray pattern horizontally compared to the hollow cone which produced spray pattern in a cyclically produced a spray pattern.

Table 2: Effect of sources of power, nozzle types and pump types on spray Swath width

Treatments	Mean Swath width (m)
Sources of Power S	
Solar only	0.65b
Solar and battery	0.86a
SE+	0.00416
Nozzle Types N	
Fan	0.796a
Hollow Cone	0.713b
SE+	0.00416
Pump Types P	
Citron	0.725b
Toyota	0.783a
SE+	0.00416
Interaction	
S*N	**
S*P	**
N*P	**
S*N*P	**

Mean followed by same letter(s) in the same column are not significantly different at *P=0.05* using DMRT. **= Significant at (P≤0.01) NS=Not significant.

Droplet size

The result of the analysis of variance (ANOVA) of the effect of the sources of power, pump types and nozzle types on the spray droplet size is presented in Table 3. The result shows that the effect of sources of power, pump types and nozzle types were highly significant on the spray droplet size at 5 % probability level. The first and second levels interaction effects of sources of power, pump types and nozzle types were highly significant on the spray droplet size except the interaction effect of pump types and nozzle types which was not significant.

The result of further analysis using Duncan Multiple Range Test (DMRT) to assess the effect of the sources of power, pump types and nozzle types on the spray droplet size indicated that solar power, fan nozzle and citron pump recorded highest mean droplet size of 320.83 µm, 320.83 µm and 317.5 µm respectively. This higher droplet size recorded by the solar power only may be attributed to the lesser voltage supplied, which in turn resulted in lower pressure of spray and therefore consequentially produced larger spray droplets.

Table 3: Effect of sources of power, nozzle types and pump types on spray droplet size

Treatments	Mean Droplet Size (µm)
Sources of Power S	
Solar only	320.83a
Solar and battery	241.67b
SE±	4.249
Nozzle Types N	
Fan	320.83a
Hollow Cone	241.67b
SE±	4.249
Pump Types P	
Citron	317.5a
Toyota	245.00b
SE±	4.249
Interaction	
S*N	**
S*P	**
N*P	NS
S*N*P	**

Mean followed by same letter(s) in the same column are not significantly different at *P=0.05* using DMRT. **= Significant at (P≤0.01) NS=Not significant.

Field performance evaluation

The result of the field performance evaluation of the solar - powered knapsack sprayer is presented below. The result of the effect of sources of power, nozzle types and pump types on effective field capacity, field efficiency and application rate were determined.

Effective Field Capacity

The result obtained shows that the effect of sources of power, pump types and nozzle types were highly significant on the effective field capacity at 5 % probability level as presented in Table 4. The first and second - level interaction effects of sources of power, pump types and nozzle types were highly significant on the effective field capacity. The result of further analysis using Duncan Multiple Range Test (DMRT) indicated that the increase in voltage power leads to increased effective field capacity from solar power only to solar panel – battery power. The solar panel power, fan nozzle and citron pump recorded selectively the highest mean effective field capacity of 0.301, 0.350 and 0.338 ha/hr respectively. The higher mean effective field capacity recorded for fan nozzle was attributed to wider coverage of fan nozzle than hollow cone nozzle.

Table 4: Effect of sources of power, nozzle types and pump types on effective field capacity

Treatments	Mean effective field capacity (ha/hr)
Sources of Power S	
Solar only	0.301a
Solar and battery	0.293b
Nozzle Types N	
Fan	0.350a
Hollow Cone	0.24b
SE±	0.00274
Pump Types P	
Citron	0.338a
Toyota	0.258b
SE±	0.00274
S*N	**
S*P	**
N*P	**
S*N*P	**

Mean followed by same letter(s) in the same column are not significantly different at *P=0.05* using DMRT. **= Significant at ($P \leq 0.01$) NS=Not significant

Application Rate

The result obtained indicated that the effect of sources of power, pump types and nozzle types were highly significant on the application rate at 5 % probability level as presented in Table 5. The first and second interaction effects of sources of power, pump types and nozzle types were highly significant on the application rate. The result of further analysis using Duncan Multiple Range Test (DMRT) indicated that the solar – battery power, fan nozzle and Toyota pump recorded highest mean application rate of 307.91 L/ha, 380 L/ha and 324.83 L/ha respectively. The solar panel power, hollow cone nozzle and citron pump recorded the least mean application rate of 280.07, 207.57 and 263.15 L/ha respectively.

Table 5: Effect of sources of power, nozzle types and pump types on application rate

Treatments	Mean Application Rate (L/ha)
Sources of Power S	
Solar only	280.07b
Solar and battery	307.91a
SE±	5.466
Nozzle Types N	
Fan	380.40a

Hollow Cone	207.57b
SE+	5.466
Pump Types P	
Citron	263.15b
Toyota	324.83b
SE+	5.466
Interaction	
S*N	**
S*P	**
N*P	**
S*N*P	**

Mean followed by same letter(s) in the same column are not significantly different at *P=0.05* using DMRT. **= Significant at (P≤0.01) NS=Not significant

Field Efficiency
The result obtained shows that the effect of sources of power, pump types and nozzle types were highly significant on the theoretical field capacity at 5 % probability level. The first and second level interaction effects of sources of power, pump types and nozzle types were highly significant on the field efficiency.
The result of further analysis using Duncan Multiple Range Test (DMRT) to assess the effect of the sources of power, pump types and nozzle types on the Field efficiency is presented in Table 6. The solar panel – battery power, hollow cone nozzle and citron pump recorded selectively highest mean Field efficiency of 82 %, 86 % and 88 % respectively. Whereas, the conventional lever operated knapsack sprayer recorded field efficiency of 90 % and 89 % for hollow cone and fan nozzle respectively.

Table 6: Effect of sources of power, nozzle types and pump types on field efficiency of the solar knapsack sprayer

Treatments	Mean Field efficiency (%)
Sources of Power S	
Solar only	76b
Solar and battery	81a
SE+	0.642
Nozzle Types N	
Fan	82b
Hollow Cone	88a
SE+	0.642
Pump Types P	
Citron	88a
Toyota	72b
SE+	0.642
S*N	**

S*P	**
N*P	**
S*N*P	**

Mean followed by same letter(s) in the same column are not significantly different at *P=0.05* using DMRT. **= Significant at (P≤0.01) NS=Not significant.

Conclusion

The solar-powered variable voltage knapsack sprayer was designed to make pesticide application more efficient. Its performance was also assessed in the lab and in the field. Spray flow rate, spray volume distribution pattern, spray swath width, droplet size, effective field capacity, field efficiency, and application rate were all considered as performance indicators. The highest mean spray flow rate of 679.33 ml/min, a swath width of 1.05 m, droplet size of 416.67 m, and droplet density of 160 per square area were recorded in the laboratory performance results, while When both hollow cone and fan nozzles were used on the solar-powered sprayer, the field efficiency was found to be uniform (approximately 98%), implying that the solar-powered sprayer was more cost-effective. As a result, the solar power sprayer could be a better spraying technique than the lever-operated knapsack sprayer in terms of efficiency, cost-effectiveness, and drudgery in pesticide application. The sprayer was estimated to cost N34, 100:00.

Conflict of Interest

The authors declare no potential conflict of interest

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