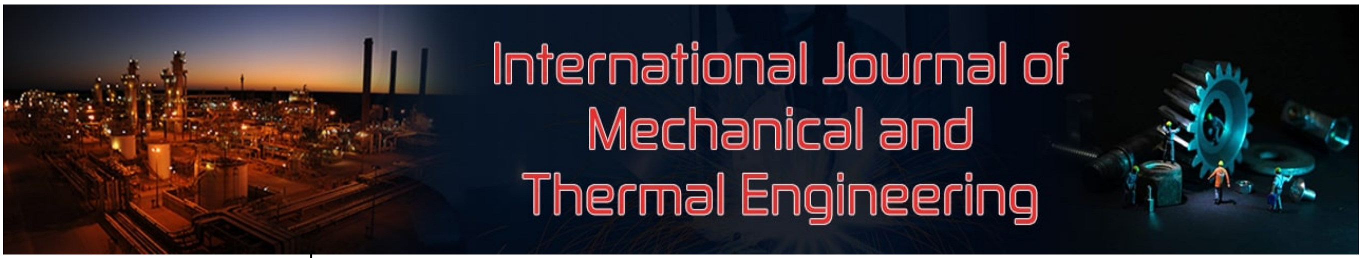

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Development and evaluation of solar-powered sprayer for large fruit trees pesticide

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Abstract
The spraying of pesticides is an important task to protect crops from insects for obtaining high yields. The hand-operated sprayer is one of, labour intensive and time-consuming method, which decreases productivity due to low capacity per unit of time. Hence, to overcome this work drudgery design solar-powered faring foliar or pesticide sprayers that solve the best alternate solution and better operation for large fruit trees. Therefore, the aim of this study was to develop and evaluate solar-powered agricultural sprayers for vegetable and fruit trees. The system was designed by considering different parameters; spraying capacity, basic raw material, environmental and crop condition, operating and coverage of area per unit time. The experiment was arranged in factorial Randomized Complete Block Design (RCBD) with six treatments replicated 3 times. Treatments: 3 hose diameter and 3 length hose. The machine has capacity of 0.25 ha/hr. The actual area coverage and discharging rate of 1.32 lit/min, as well as the efficiency of the machine, was 79.4%. This value was coincided with the average fruit tree of the study area. Based on the tested result, the sprayers produce the best booming uniformity and droplet size at six diameters at nine meter (9 m) vertical height that is better technology for large fruit trees like mango and avocado as well as agro-forestry foliar and chemical application and should promote for farming communities boosting agricultural production and productivity.

Keywords: Solar panel, DC battery, DC pump, hose, nozzle, foliar, sprayer

Introduction

Agriculture is a profession of many tedious processes and practices, one of which is the spraying of pesticides in the farm fields. Sprayers are mechanical devices that specifically designed to spray liquids quickly and easily. The spraying of pesticides is an important task in agriculture for protecting the crops from insects and currently used for foliar application. In developing countries like Ethiopia farmers mainly used manual, hand-operated sprayers for this task. This operation conducted through a backpack spraying mechanism, which is fitted with as harnessed human back to carry and operate by hand. A hand lever continuously operated to maintain pressure makes the backpack sprayers output uniform and handheld sprayers. Basically, this type sprayers are low-cost backpack sprayer which, will generate only low pressure and lack features such as high-pressure pumps, pressure adjustment control (regulator) and pressure gauge found on commercial grade units according to (Joshua *et al.*, 2010) [3]. In fact, high-pressure sprayers, the designed of high-pressure sprayers that fitted with boom they can do any work done by the suitable low-pressure boom sprayers. These can also be fitted with handguns. The handgun is used for spraying shade trees and ornamental, livestock, orchards, building, unwanted brush, rights-of-way, and commercial crops used for reduce drudgery, and hazardous of chemicals (Riley and Siemen, 2003) [1].

Besides high tech. and heavy-duty multipurpose sprayer. Low-cost and multipurpose smallholder farmers were crucially important for large fruit trees and other crop protection. The sprayer of this type was a great way to use for large fruit trees like; mango and Avocado for over height and as well as over ground spraying processes. Hence, rethinking and reversed engineering in developing countries for availing technology options is very important. Conspicuous Solar energy-based pesticides sprayer are the ultimate cost-effective solution at the locations where spraying is difficult.

Materials and Methods

Description of the machine components

The main components of the machine consist of frames, a fluid storage tank and seat, a high-speed DC motor with filter, a battery, a solar panel, a power supply circuit, a hose and a nozzle (Table 1). After the necessary design and specification was completed basic material, selection for construction of the machine/sprayer made. The sprayer manufactured in Fadis Agricultural Research Center, Agricultural Engineering Workshop. Accordingly, the evaluation of manufactured sparer commenced on the papaya, avocado and mango tree in Babile and Fadis districts since 2019. Both districts were situated in East Hararghe zone of Oromia Regional State of 1885 m A.S.L. with a point location of $09^0$18'09" N latitudes and 42^0 07' 03" longitude respectively.

Table 1: Material specification of solar-powered sprayer

Sr. No.	Description	Specification
1	Fluid storage/Tank	PVC, 15-20 Lit
2	Solar panel	20 Watt PV solar panel:- Dimension: 540 x 350 x 25 mm, Weight :1kg, Max voltage:17 V, Max current: 1.18 Amp, Tolerance: ± 5%
3	Charge controller	Capacity 12V, 5Amp
4	Battery	Sealed lead acid battery:- Capacity: 12V, 9 Amph. dimension: 15 x 9 x 6 cm, weight:2.5 kg; max initial current= 2.4 A, cycle use :14.5-14.9 V
5	Motor	Brushless DC motor Capacity:12 V, 1.2 A, :0 - 6000 rpm
6	Hoses	Diameter: 6, 8 and 10 mm diameter types ¼ standard
7	Metal parts	Wheelchair wheel, angle iron, square pipe, electric wire 1.5, metal pipes
8	Switch	Push button type switch
9	Hardener	Epoxy

Solar panel: The solar panel/photovoltaic system can be used to collect solar energy for generating and supplying electricity current. Based on the designed sprayer's power source required selection of solar panels was conducted as described in Table.1

DC motor: High-speed DC motor is used to pressurize and lift fluid from the tank to the required head.

Battery: Is an electrochemical cell storage with externally connected provided to power electrical devices. When a battery is supplying electric power, its positive terminal is the cathode and its negative terminal is the anode.

Storage tank: Storage tank or container used to hold liquid when required spraying on selected crops, or fruit trees. Storage tanks are available, based on type and size; in this case, the selected fluid storage tank was a Knapsack with capacity of 15 liter.

Nozzle: A nozzle is a device designed to control the direction or characteristics of a fluid flow (Krishna, *et al.* 2017) [6]. A nozzle is often a pipe or tube of varying pressure and fluid viscosity. For this purpose nozzle, selection was done directly from FAO, (2001) [7] standard manuals guide as 110º flat fan type.

Solar panel and tank support frame: It is used to support all the sprayers system and manufactured from angle iron, square pipe and; wheel for movability. The main functions of a frame are to support the tank components and all accessories of sprayers, without undue deflection or distortion.

Nozzle and hose support frame: Manufactured from 30, 25 and 20 mm by 3 mm thick square pipes of 4, 3, and 2.5 m length respectively in accordance of telescopic mode for elongating purposes. At 2 m, vertical height from handlebar jointer fixed together with hollow shaft of 1.27 cm diameter and 25 cm length to insert into 2.54 cm hollow shaft at the top of the vertical arm. The operator at handlebar carried the hose internally and rotate at 360^0 guiding the horizontal arm.

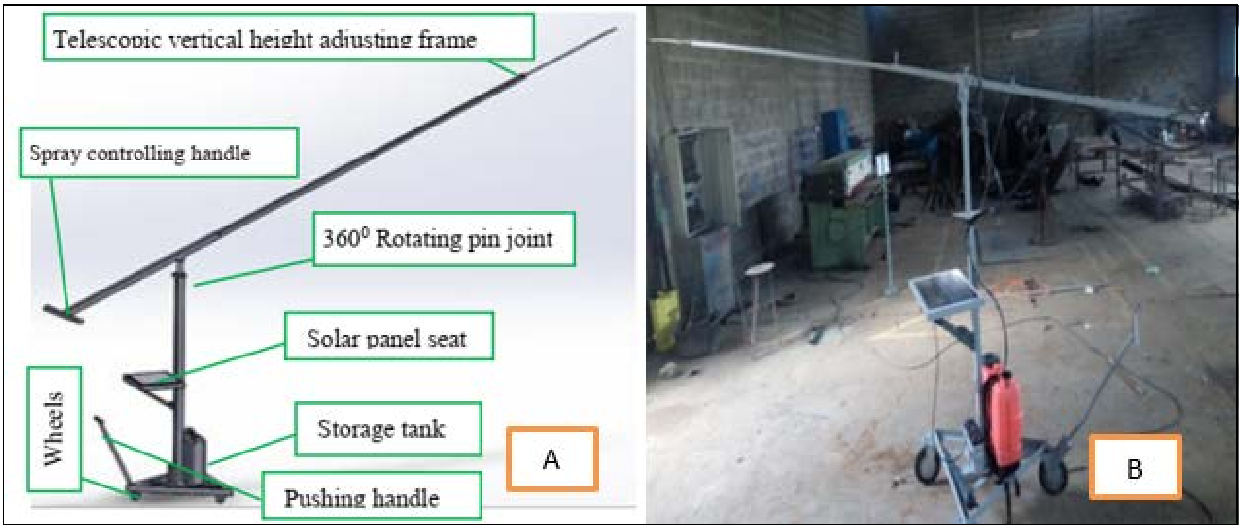

Fig 1: A-3D frame design; B - fully Assembled prototype of solar-powered sprayers

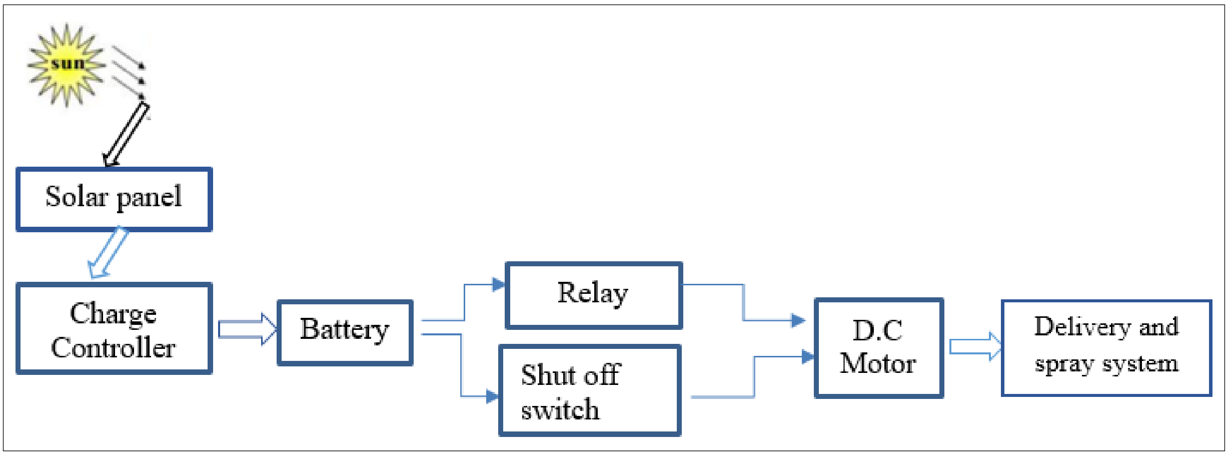

Fig 3: Operation mechanism of solar-powered sprayer

Experimental design and statistical analysis

The experimental has factorial arranged in randomized complete block design (RCBD). The treatments are namely: Three hose diameters (Φ): 6, 8 and 10 mm, and 3-nozzle length/ height positions (3, 6 and 9 meter). Each treatment was replicated three times. All measured variables were subjected to Genstat 15th edition software for analysis of variance. The mean separation made using (LSD) the least significant difference at a 5% level of probability.

Table 2: Experimental treatments

Treatment	Hose Diameter in (mm)	Nozzle Height/Position (m)	Treatment combination
T_1	6	3	6 mm Φ hose at 3 m nozzle height
T_2		6	6 mm Φ hose at 6 m nozzle height
T_3		9	6 mm Φ hose at 9 m nozzle height
T_4	8	3	8 mm Φ hose at 3 m nozzle height
T_5		6	8 mm Φ hose at 6 m nozzle height
T_6		9	8 mm Φ hose at 9 m nozzle height
T_7	10	3	10 mm Φ hose at 3 m nozzle height
T_8		6	10 mm Φ hose at 6 m nozzle height
T_9		9	10 mm Φ hose at 9 m nozzle height

Data collected

Parameters collected during the test include droplet size, boom uniformity, spray height, and discharging rate. In addition to this data total battery charging and discharging time, operating time, spraying capacity and pumping efficiency were collected.

Machine performance

Field capacity: To determine actual field capacity, time consumed for real work and time lost for different activities such as cut-off time, and tank-filling time was taken into consideration. Time required for actual field operation and time lost measured by stopwatch. However, the time lost for recharging the battery, and fixing the sprayer trouble shoot neglected, because usually, it accomplished before starting fieldwork. Accordingly, for field performance evaluation, the average operation speed is taken from operator. The assumptions coverage area (trees canopy) is in the form of sector of a spherical shape and the operator controls the working path.

$$\text{Actual Field Capacty} = \frac{\text{Actual Area coverd (ha)}}{\text{Total time required to cover ha (hr.)}} \quad (1)$$

$$\text{Theoretical field capacity} = \frac{\text{Theoretical width (m)} * \text{Speed (km/h)}}{10} \quad (2)$$

Power conversion efficiency

Sunlight is converted by solar panels to energy, hence panels' of the solar cell power conversion efficiency was determined according to (Joshua, *et al.* 2010) [3].

The power calculation is determined according to (Sootha and Gupta, 1991) [4].

Power = Voltage * current

Battery duty/operating time (Bt) calculated by

$$\text{Bt} = \frac{\text{Power stored in battery}}{\text{Power Consumed by motor (pump)}} \quad (3)$$

Pump efficiency: It measures how effectively the motor utilizes the power supplied by the battery in delivering with constant pressure to the hose.

$$\text{Pumping efficiency (\%)} = \frac{\text{power required to deliver liquid}}{\text{power supplied by the solar panel}} * 100 \quad (4)$$

Result and Discussion

Determination of solar panel and battery output characteristic

To calculate the output characteristics of the whole system i.e. maximum voltage and current generated denoted by manufacturers' was taken as $V_{max..}$ = 17 and I_{max} = 1.18 A respectively. Thus the maximum power (P_{max}) generated by solar panels as ($P_{max} = V_{max} * I_{max}$), which was 20.07 Wh. Similarly, the maximum out power of the battery was

calculated in the same manner as 108 Whir. accordingly, battery charging time and fully charged operating time was determined as follows.
Battery maximum charging time is T_{max} = P_{max} stored by battery divided by P_{max} generated by solar panel as 5.4 hr. However, charging time varies with intensity of sun radiations at different rates with respect to the solar panel. Battery operating time depends on load required by the pump unit. Thus, According to manufacturers, the maximum load required by a high-speed DC motor pump as 18 watts. Hence, the maximum battery operating time calculated as the ratio of power stored in the battery to the power consumed by the pump, which was equal to 6 hr.

Pump Efficiency: The power required to deliver liquid was 18 W and the power supplied by solar panel 20.07 W. Thus, the calculated pumping efficiency found as 89.7%. Therefore, the required energy for the designed sprayer is 20 W solar panels and a 12 V DC motor is selected. For continuous power, supply, to the spraying system, equipped with rechargeable battery cell of (12V, 9 Ah) preferably.

Sprayer field efficiency: The sprayer was evaluated on local mango variety having different heights, to actual field capacity, and theoretical field capacity using (equation). The area of the local mango canopy was spherical in shape of average radius of 5 m.

A = $4\Pi r^2$ = 314 m^2 = 0.0314 ha and time to cover this area = 0.125 hr.

$$= \frac{0.0314 \text{ ha}}{0.125 \text{ hr}} = 0.25 \text{ ha/hr.}$$

$$\text{Theoretical field capacity} = \frac{\text{Theoretical width (m) x Speed (km/h)}}{10}$$

$$= \frac{1.9 \text{ m x } 1.66 \text{ (km/h)}}{10} = 0.315 \text{ ha/hr}$$

$$\text{Field efficiency} = \frac{\text{Actual field capacity}}{\text{Theoretical field capacity}} * 100$$

$$= \frac{0.25}{0.315} * 100 = 79.4\%$$

Field performance of solar power sprayer

Effect of hose length and diameter on droplet size

ANOVA indicated that droplet size of the sprayed fluid was significantly different (p<0.05) affected by both hose diameter and length. The larger and lowest droplet size of 2.28 and 0.693 mm, were recorded by 10 mm hose diameter at 9 m spraying height. This shows that both hose diameter and height of the nozzle have a significant effect on droplet size. Specifically, the result indicated that, as hose diameter increases droplet size increased.

Table 3: Mean values of performance test

Treatment combination	Droplet size (mm)	Boom/Uniformity (inch)	Area Coverage (ha)	Discharge rate lit/min
6 mm Φ hose at 3m length	0.816a	0.53a	1.19c	2.013ab
6 mm Φ hose at 6 m length	0.693a	0.997ab	0.8133bc	1.78ab
6 mm Φ hose at 9 m length	0.927a	1.43ab	0.3567ab	1.32a
8 mm Φ hose at 3m length	1.55[a]	2.263abc	0.1667a	2.8c
8 mm Φ hose at 6 m length	0.827a	1.913ab	0.37ab	1.877ab
8 mm Φ hose at 9 m length	0.787a	2.54bc	0.36ab	2.073b
10 mm Φ hose at 3m length	1.53ab	2.093abc	0.2633ab	2.83c
10 mm Φ hose at 6 m length	1.6ab	2.26abc	0.3867ab	2.037b
10 mm Φ hose at 9m length	2.283b	3.737c	0.1233a	1.527ab
CV (%)	30.7	46.5	68.2	18.3
L.S.D (%)	0.818	1.59	0.5289	0.6423

Effect of hose length and Diameter on boom uniformity

ANOVA indicated that boom uniformity of sprayer fluid was significantly (p<0.05) affected by both hose length and diameter. The lowest gap in between droplets (booming uniformity) observed as 0.53 mm from 6 mm diameter of hose at 3 m nozzle vertical length or height, whereas the largest droplet distance was produced as 3.74 mm by 10 mm hose at 9 m length. This shows that the best boom uniformity pattern is produced at the smallest hose diameter and short length, which agrees with the result of (Foques and Nuyttens, 2011a), 255 and 588-micrometre knapsack sprayer booming patterns recorded at laboratory. Generally, booming pattern shows increasing trends as the hose length and diameter increases. Moreover, the accuracy of taking boomed droplet distance measurement affected by natural factors like wind and sun, which resulted in droplet size dropping or expanding more than nature of the boom before measuring.

Effect of hose length and Diameter on area coverage

Area coverage or boom diameter of **the** sprayer was highly significantly (p<0.01) affected by both hose diameter and length. The highest and lowest mean values of area coverage recorded as 1.19 and 0.123 ha by 6 mm and 10 mm hose Φ at 3 m vertical nozzle height respectively (Table 3). This shows that both pipe/hose diameter and length /height have significant effects on fluid pumping capacity of the motor. Moreover, the result revealed that, as hose diameter and length increase flow velocity/pressure decrease or booming capacity of the nozzle decrease, because of pressure loss due to pipe diameter as well as, hose length. This means area coverage has direct relationship with the amount of fluid discharged per unit time of application. Therefore, the selection of optimum area coverage on the bases of hose diameter and length and required discharge economically important, by keeping other parameter (power source and motor capacity) constant. Hence, the optimum area or booming capacity observed, as 6 m vertical height with 6 mm hose diameter first option followed by 8 and 10 mm as the best to effective spraying capacity per unit time.

Effect of hose length and diameter on discharge

ANOVA revealed that flow rate or discharge of fluid is highly significantly ($p<0.01$) affected by both hose diameter and length. The highest and lowest mean flow rate produced as 2.85 and 1.32 lit/min recorded by 10 mm hose Φ at 3 m length and 6 mm hose Φ at 9 m length respectively. This shows that the flow rate or discharge of fluid was significantly affected nozzle height. Accordingly, as the spraying height position increase discharge rate show decrease trended. This may be due to pressure head loss or friction loss.

Conclusion and Recommendation

As observed from the above result the solar-powered sprayer was best alternative in order to alleviate the problem of spraying on long fruit trees. The sprayer has important spraying merit in relation for selecting right type of spaying head, on the base of hose diameter /nozzle position height. Therefore, the selection of optimum area coverage on the bases of hose diameter and length and required discharge economically important, by keeping other parameter (power source and motor capacity) constant. Hence, the optimum area or booming capacity observed, as 6 m vertical height with 6 mm hose diameter first option followed by 8 and 10 mm as the best to effective spraying capacity per unit time.

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