



Research Article

Sustainable Solar Powered Multi Nozzle Pesticide Sprayer for Improved Production

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ABSTRACT

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In agriculture, automation of spraying has boosted farm productivity. As a result, the labor issue has been resolved. However, the situation is different in a nation like Pakistan. Automation in the agricultural sector is challenging in these arid regions because the most Pakistani farmers are struggling financially. Therefore, the wide use of the manually operated sprayer is still common in majority of the areas of Pakistan. Due to its affordability, design, and versatility, manually lever driven backpack sprayers are much sought after by small-scale farmers. Two types of sprays are utilized in Pakistani farms: fuel-operated pumps and hand-operated ones. The primary disadvantage of a hand-operated spray pump is that its user cannot use it continuously for longer than five to six hours. Due to fatigue, long working hours are impossible without integration of any other energy, but a gasoline-operated spray pump needs fuel, which is costly and difficult to find in remote areas. Therefore, the work represents the integration of renewable energy (solar power) and a manually operated mechanism to achieve sustainability with increased efficiency and reduced human efforts. It is observed from the results that around 2.5 times increased discharge was achieved, and time is reduced by 2.5 times. The proposed idea drives a solar powered multi-nozzle with pump, which sprays pesticide uniformly, along with environmental benefits. In result, pesticide sprayer reduces farmer fatigue and sprays at its highest pace in the shortest amount of time without requiring fuel.

1. Introduction

More than three-quarters of Pakistan's populace relies directly or indirectly on agriculture, a practice entrenched for centuries but still prevalent today. The traditional methods of applying fertilizers and pesticides require a significant amount of time and labor, which emphasizes the need for improved spraying techniques. With a burgeoning population and rapid industrialization, there is an urgent imperative to modernize agricultural practices. Challenges such as planting delays, improper distribution of herbicides and fertilizers, and suboptimal harvesting procedures plague numerous farms. The insufficiency of electricity and deficient agricultural mechanization are identified as major factors contributing to diminished output in farming operations [1,2].

The implementation of automation holds a potential to address low production levels by facilitating a more efficient and equitable distribution of labor. This technological advancement reduces resource requirements, minimizes input losses, and mitigates waste, thereby enabling farmers to maximize output while saving costs. Pakistan's agricultural output predominantly comprises vegetables, grains, pulses, and spices, with wheat production and exports anticipated to experience significant growth in the foreseeable future [3,4]. Rice, cotton, and sugarcane stand out as pivotal crops in

Pakistan, contributing to the country's substantial agricultural exports. Additionally, commodities like potatoes, tomatoes, and onions hold significant importance as key vegetable crops, collectively constituting a notable portion of global vegetable production. Of these, tomatoes emerge as particularly crucial both in terms of revenue generation and nutritional value. Encouragingly, there is a growing trend towards transitioning from conventional energy systems to renewable sources, highlighting the need for a similar transformation within the agricultural sector. [5].

Ensuring crop protection from pests and diseases is crucial for optimizing yields, as agricultural pests pose significant threats to many crops [6]. Effective plant protection is essential to minimize losses and enhance the efficiency of other production inputs [7]. Achieving effectiveness in chemical application for pest management necessitates careful management, rationing, and efficient spraying techniques. Chemical application, being the only fully automated activity in agriculture, requires specialized equipment and plays a vital role in farming practices. The utilization of a specialized instrument known as a "Sprayer" facilitates the application of herbicides, insecticides, and fertilizers to agricultural crops, yielding optimal results with minimal effort [8]. The advent of pesticides, fertilizers, and sprayers has catalyzed an agricultural revolution. Various chemical application machines, such as knapsack sprayers, ultra-

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low volume sprayers, and tractor boom sprayers, have been developed in the past to address these needs [9]. Commonly used pesticide and herbicide spraying equipment includes large tractor-mounted sprayers and smaller backpack devices, both are operated manually. In response to the challenges posed by these conventional sprayers, a manually operated wheel-driven sprayer has been proposed, primarily aimed at reducing human effort. This innovative sprayer is designed to maximize the rate of pesticide application within minimum time frames through a wheel-operated mechanism [10]. Targeting smaller industries and small gardens, this wheel sprayer eliminates the need for heavy manual knapsack sprayers carried on the back during spraying sessions. Unlike traditional methods, the proposed wheel sprayer only requires a forward push for operation in the field, significantly reducing both time and effort [11]. Moreover, with a single operator, this wheel sprayer can effectively apply spray solution on both sides of its forward motion, enabling enhanced coverage and efficiency compared to standard knapsack sprayers.

This pesticide sprayer is fully powered by solar energy with Solar PV module of 150 watt commercially available, unlike traditional sprayers that use fossil fuels for power [12]. This encourages more sustainable agricultural practices by lowering operating costs for farmers as well as carbon emissions. The distribution of pesticides is made more uniform and effective by the addition of multiple nozzles. Compared to conventional single-nozzle sprayers, this design minimizes environmental impact and requires less pesticide. Our system's engineering optimizes the spraying process to increase production. Precise control over the use of pesticides guarantees improved control over pests, which promotes healthier crops and higher yields. Both small and large-scale farmers can use the sprayer because of its easy-to-use design and simple operating procedures. Furthermore, using solar energy considerably lowers.

However multiple problems are faced due to conventional sprayer such as Heavy weight of sprayer causes difficulty in carrying on backside or shoulder of operator, Fatigue due to heavy weight, Heavy weight reduces the efficiency of the operator, big size of pump cause inconvenience to the operator, Poor selection and quality of equipment. Due to above stated problems following solutions were taken into account as to select the placement and size of nozzles, design of the sprayer with proper adjustment facility with respect to crop size & height, the performance analysis of the developed wheel sprayer, calculate the area covered with respect to the flow rate of pesticides and time [13].

2. Literature review

The integration of the Pesticide Drone with Sprinkler Mechanism signifies a significant advancement in agricultural technology, merging drone capabilities with precise irrigation methods to tackle industry challenges such as water optimization and crop management. Equipped with sensors and real-time data analysis, this innovation ensures efficient water distribution, thereby reducing wastage and labor costs [14]. Concurrently, Joshua's research on the "Solar Sprayer - An Agriculture Implement" delves into the transition from fossil fuel-powered sprayers to solar-powered alternatives, utilizing solar photovoltaic (PV) technology [15,16]. This study underscores the viability of solar sprayers as eco-friendly substitutes for traditional sprayers, offering sustainable solutions to agricultural practices while addressing global concerns regarding water scarcity and environmental sustainability [17].

In response to the imperative need for increased agricultural productivity with minimal human effort, various studies have endeavored to enhance the efficiency of pesticide sprayers and agricultural mechanization. Poratkar and Raut [18] focused on the development of Multi-nozzle Pesticide Sprayer Pumps,

emphasizing the importance of maximizing spray output within limited time frames through the utilization of manual multi-nozzle pesticide sprayer pumps [19]. To mechanize agricultural processes to meet rising food demands, Raut studied agricultural sprayers with weeders. This would maximize productivity while conserving resources [20]. Subbarayudu and Venkatachala Pathi [21] contributed to this effort through their research on the development of pedal operated sprayers, seeking to reduce user effort while enhancing pedal-to-pump reciprocation and discharge rates using a crank mechanism. Their work resulted in the creation of a pedal-operated sprayer with improved efficiency in pesticide and insecticide application in fields and orchards. Similarly, these endeavors underscore the urgency and importance of incorporating solar energy, as demonstrated by Joshua's research on the Solar Sprayer - An Agriculture Implement, into agricultural technologies to optimize productivity while reducing labor demands and environmental impact [22].

3. Working of Solar Operated Wheel Sprayer

The operation begins with the operator grasping the handle and applying minimal force to initiate forward movement. A 12 V battery is used to cover the shading effect of PV module and supply uninterrupted power to pump for spraying. It is charged when the prototype is in stationary condition. When there is cloudy season, the power is consumed from the battery source. Simultaneously, the system necessitates manual initiation as the cart commences its forward motion. Subsequently, solar energy captured by the panel undergoes conversion into electrical power, which is then stored within a battery. This stored power is channelled through a DC pump, pressurizing the insecticides or pesticides for flow through the connected pipe.

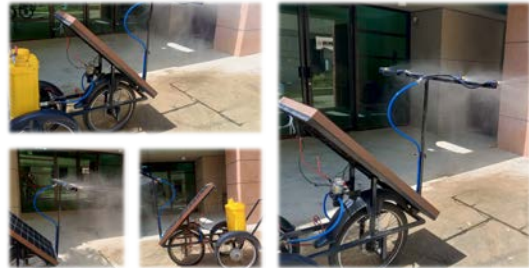


Fig. 1 Prototype During Spraying

The pipe, in turn, directs the fluid towards a series of nozzles via a nozzle shaft, maintaining a predetermined pressure. Ultimately, the multi-nozzle assembly affixed to the nozzle shaft commences spraying the field, facilitated by the pressure generated by the pump. Additionally, manual adjustment of the nozzle shaft is achievable through screw locking mechanisms, enhancing operational flexibility and control.

3.1. Frame Stress Analysis

During the initial phase, the previously developed manually operated multi-nozzle pesticide sprayer underwent analysis to evaluate stress distribution and stress profiles. This examination revealed that the frame experienced stress under the applied load, which encompassed the weight of the solar PV plate, as illustrated in Figure 2.

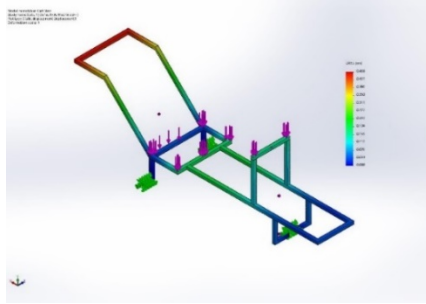


Fig. 2 Stress Analysis of Frame

Following careful observation of the contours, the frame underwent a redesign process, culminating in the preparation of its solid model using SolidWorks software. Subsequent analysis revealed that the redesigned frame exhibited commendable stability, effectively supporting the weight it was intended to carry as shown in figure 3.

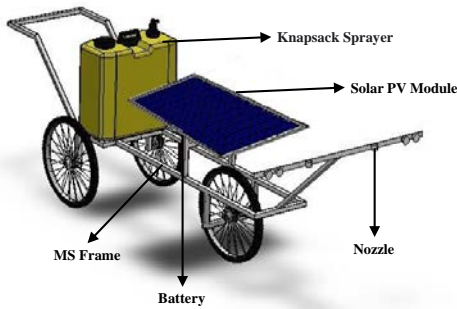


Fig. 3 CAD Solid Model

Figure 4 clearly illustrates the connection of the pipelines with the pump and nozzle system. The diagram shows the specific arrangement and integration of these components, highlighting how they work together to facilitate fluid movement. The pressure within the system was calculated based on the configuration and operational parameters depicted in the figure.



Fig. 4 Fabricated Project

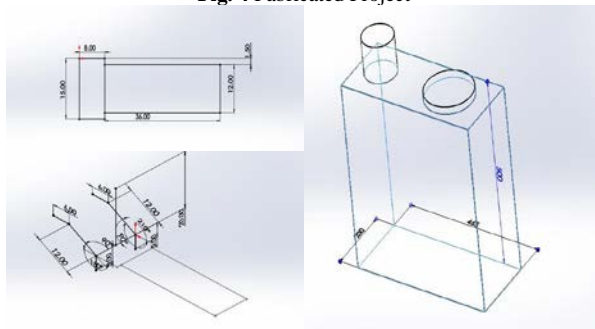


Fig. 5 Dimensions of 3D Model (all units are in mm)

The total cost for this prototype was approximately forty-five thousand Pakistani rupees (PKR). The detailed breakdown

of costs for each component is provided in the Table 1.

Table 1 Cost of Each Component

Material/Parts	Price (PKR)
Driving sprocket (16 teeth), Driven Sprocket (48 teeth), Chain	2500
Wheel of 20 inch	2000
Spray Pump of 20L	5,000
Nozzles (Hollow Cone Nozzles)	3000
Mild Steel Square bar	4000
Solar PV Module (150 Watt)	12000
12 Volt Rechargeable Battery	12000
Other Expenses	5000
Total	45,500

3.2. Equations for Design

Since the equations are utilized for designing chain and sprocket mechanisms to increase transmission efficiency and work power, several key factors and principles must be considered in the engineering and calculation process. The following equations are applied to optimize such mechanisms: [23].

For Wheel

$$S = 2\pi r \tag{1}$$

For transmission of motion

$$i = \frac{T_2}{T_1} \tag{2}$$

$$CD = 30P \text{ or } 50P \tag{3}$$

$$L = KP \tag{4}$$

$$x = \left[k - \frac{T_1 + T_2}{2} + \sqrt{\left(k - \frac{T_1 + T_2}{2} \right)^2 - 8 \left(\frac{T_2 - T_1}{2\pi} \right)^2} \right] \tag{5}$$

$$PD = \frac{P}{\sin\left[\frac{180}{N}\right]} \tag{6}$$

4. Results and Discussion

A performance evaluation was conducted to compare the efficacy of manually operated multi-nozzle sprayers and solar-powered sprayers in terms of result parameters and calculations. The experiment involved spraying a designated area measuring 2m x 30m, as depicted in Figure 6, for a total of five repetitions using both types of sprayers. The duration of spraying was measured using a stopwatch for both the manual and solar-powered sprayers, as well as for a knapsack hand sprayer for comparative purposes. Subsequently, the obtained results were analyzed and juxtaposed. The assessment of the solar-powered sprayer's performance involved its application in the field, where the discharge of the sprayed solution was measured to ascertain its practical effectiveness. Both theoretical and actual field capacities were calculated based on the observed readings. Furthermore, field efficiency was determined to assess the performance of the solar-powered sprayer equipped with a chain and sprocket mechanism.



Fig. 6 Field Selected for Testing

Figure 7 clearly depicts that the average speed of solar powered sprayer is less than that of manually operated multi

nozzle sprayer. In this figure red bar denotes manually operated and blue bar denotes solar powered. But overall, the average speed is same.

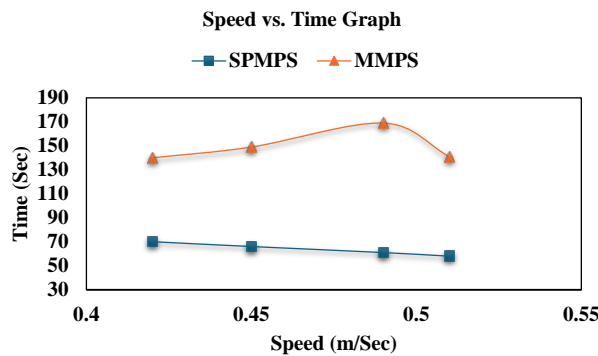


Fig. 7 Comparison of average working speed between SPMPS and MMPS

Figure 8 demonstrates that the overall discharge rate of the solar-powered mechanism significantly exceeds that of both the hand-pumped sprayer and the chain and sprocket mechanism. This increased discharge rate suggests a more efficient fluid delivery system, as the solar-powered mechanism can dispense a greater volume of fluid within a shorter timeframe. The solar-powered system benefits from utilizing solar energy, which provides a consistent and potent energy source to drive the pumping mechanism. In contrast to the hand-pumped sprayer, which depends on manual labor, and the chain and sprocket mechanism, which converts human mechanical energy, the solar-powered system ensures a higher and more stable discharge rate while minimizing physical effort for the user.

Additionally, the adoption of the solar-powered mechanism offers significant environmental advantages. By harnessing renewable solar energy, the system reduces dependence on fossil fuels and lowers carbon emissions, aligning with global initiatives to combat climate change and promote sustainable technologies. The solar-powered mechanism's reduced carbon footprint makes it an attractive option for environmentally conscious users and contributes to broader sustainability goals. In conclusion, Figure 6 highlights that the solar-powered mechanism not only improves operational efficiency with a higher discharge rate but also supports environmental sustainability through the reduction of carbon emissions.

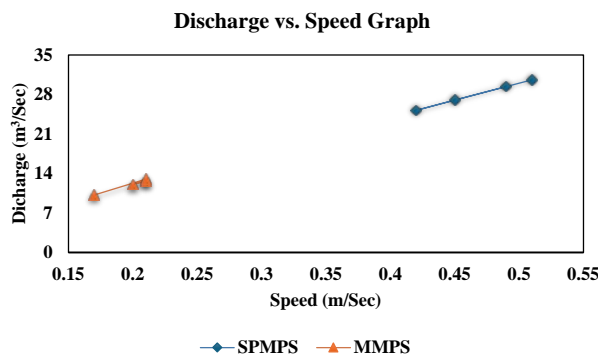


Fig. 8 Discharge comparison between SPMPS and MMPS

5. Conclusions

The comparative analysis conducted from this study provides compelling evidence for the superiority of solar powered pesticide sprayer over the multi-nozzle mobile compression pump sprayer (MMPS) in agricultural contexts. The SPMPS demonstrates significantly higher working speed and discharge rate, leading to improved productivity and reduced spraying time with zero carbon mission and minimum human effort involved. Furthermore, the observed discharge in the solar powered sprayer

was very low, because it could be controlled through a switch, whereas MMPS was directly connected with the chain and sprocket. So, in this context less pesticide was used, which directly increased the productivity. These findings highlight the potential of MMPS as an asset in modern farming practices, warranting further consideration and adoption in agricultural operations.

6. Futures Scope

Considering future scope, expanding the nozzle count from 3 to 6 offers potential to bolster field capacity. Additionally, the integration of two supporting wheels enhances manoeuvrability across diverse terrains. Furthermore, incorporating a cut-off valve within the boom assembly mitigates spray solution wastage during turns. These proposed enhancements not only optimize operational efficiency but also align with sustainable agricultural practices, addressing contemporary challenges in pest control and resource conservation.

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Declaration of conflicting interests

The authors declare no competing interests.

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Nomenclature

S	Wheel Circumference
R	Radius of Wheel
i	Transmission Ratio
$T1$	Number of Teeth on driven sprocket
$T2$	Number of Teeth on driving sprocket
CD	Centre Distance
P	Pitch of the chain
L	Length of Chain
K	Chain Links
PD	Pitch Diameter
N	Number of Teeth on Sprocket
x	Centre Distance
	MMPS Manually Operated Multi Nozzle Pesticide Sprayer
	SPMPS Solar Powered Multi nozzle Pesticide Sprayer

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