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Design and Fabrication of an Agricultural Spraying Machine Using a Knapsack Sprayer

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Abstract
Plant protection equipment is essential in the agricultural field for increasing crop productivity and minimizing the losses caused. Specialized machinery for mechanically applying chemicals is crucial for maximizing crop yields in farming. Farmers use a wide range of pesticides to counteract the effects of insects, diseases, and fungi on their crops. The backpack sprayers do the spraying with staffing, which requires more human effort, covers a small area, is time-consuming, and has a low storage capacity. The market introduced many products to address these limitations, but they cannot work simultaneously. Solar, electrical, and chemical energy is now being used to spray pesticides, but these methods are expensive and require a trained operator. To address the issues above, a product designed with adaptable spraying equipment is proposed to benefit medium-and small-scale farmers. This study aims to look at the problem of manual backpack sprayers and reduce backpack and foot spraying, eliminate human efforts, and decrease labor costs by advancing the spraying method and a constant flow of droplets. Finally, we have investigated the effects of urging gardeners and farmers to spray their plants with liquids such as pesticides, herbicides, and water. The proposed design can help gardeners in terms of comfort during spraying, reducing energy used to pump tanks, and effectively utilizing spraying time.

1. Introduction

The spraying process is an essential method of cultivation. Usually, farmers use regular sprayer machines to disinfect the crop from pesticides, which is difficult, time-consuming, and expensive to carry. Spray machines play a vital role in spraying pesticides on crops. There are currently various spray machines available in the market (Ibrahim *et al.,* 2019). Although all these sprays look different, their primary function is the same. These sprays have many disadvantages, such as with sprays carried backward, the lever has to be pushed up and down to create pressure, which is an arduous task. Another disadvantage of the petrol spray machine is that it establishes vibrations and extra noise in the crop field. In addition to that, purchasing oil for the engine is another drawback (Poratkar and Raut, 2013), which is very expensive for the farmer.

The best way to solve all these problems is to develop a single machine with all the equipment to be used for applying pesticides through mechanical energy. Designing and building flexible equipment that will benefit medium and small-scale farmers for spraying operations is essential. The product must be easy for farmers to carry, and oil is not required to handle it. It can be easily transported from one place to another and sprayed with wheels. This study tries to make low-cost spray machines so farmers can afford them. According to the concept of this study, try to build a small agricultural reciprocating multi-sprayer that is mechanically operated by a slider crank mechanism (Prashant *et al.,* 2022). Moreover, Plant protection activities are essential practices during crop production — application of maximum pesticide products with the sprayer. The application of fungicides, herbicides, and insecticides is one of agriculture's most recurrent and significant tasks. Conventional agricultural

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spraying techniques have made the inconsistency between economic growth and environmental protection in agricultural production (Siddharth *et al.*, 2016).

Day by day, the population of Bangladesh is increasing and to fulfill the need for food modernization of agricultural sectors is important. Because of chemical fertilizers, the fertility of the soil is decreasing. Hence, farmers are attracted to organic farming. By mechanization in spraying devices (Venkatraman *et al.*, 2018), fertilizers and pesticides are distributed equally on the farm and reduce the quantity of waste, which results in the prevention of losses and wastage of input applied to the farm. It will reduce the cost of production. Mechanization gives higher productivity with minimum input. Farmers are using the same traditional methods for spraying fertilizers and pesticides. Equipment is also the same for ages. In Bangladesh, there is a large development in industrial sectors compared to agricultural sectors. Conventionally (Joshua *et al.*, 2010), the spraying is done by laborers carrying backpack sprayers and fertilizers are sprayed manually. The efforts required are more beneficial by farmers having small farming land. According to (Fox *et al.*, 2003), chemicals are widely used for controlling disease, insects, and weeds in crops. They can save a crop from pest attack only when applied in time. The chemicals are costly. Therefore, equipment for uniform and effective application is essential. Dusters and sprayers are used for applying chemicals. But spraying techniques have continuously developed in recent decades. Unfortunately, this is not the case in usable traditional farming practices. Problems with the advanced spraying technologies are: (1) Advanced spraying technologies come with expensive components which are not affordable for all farmers, (2) Farmers are not familiar with advanced spraying technologies and their complex operations, and (3) Unavailability of its spare components for repair. Keeping all these setbacks in mind, try to come up with a solution. To overcome these difficulties, try to work on its solution from the perspective of our farming practices, so it can contribute to the economic growth in agricultural production.

Performance of a chemical injection sprayer system (Balashanmugam *et al.*, 2021; Thakkar *et al.*, 2017) found the time delay of concentrated pesticides through injection sprayers to be significant and proposed injection at the individual nozzles as a possible solution to shorten delays. Simulation of chemical application accuracy for injection sprayers. In (Mbayaki and Kinama *et al.*, 2022), an autonomous mobile robot for use in pest control and disease prevention applications in commercial greenhouses. They developed the robot platform's ability to successfully navigate itself down rows of a greenhouse while the pesticide spraying system efficiently covers the plants evenly with spray in the set dosages. Autonomous Pesticide Spraying Robot for a Greenhouse. Deshpande (2017) developed a system like a centrifugal pump is the most common non-positive displacement pump. The output from this type of pump is influenced by pressure. A key component of the centrifugal pump is the throttling valve. A manual throttling valve on the main output line is essential for the accurate operation of the centrifugal pump. Using herbicides has replaced much of the mechanical tillage done formerly. Chemical application is made with attachments to tillage machines and seeders or with single-purpose chemical application.

2.1 Design concept of a spraying machine

In the agricultural sector, the farmer uses the traditional way which is spray carried on a backpack and spraying the crop. This becomes time-consuming, costly, and human fatigue is a major concern. These problems can be overcome by using agricultural reciprocating multi-sprayers. It facilitates the uniform spread of the chemicals, is capable of throwing chemicals at the desired level, precision made nozzle tip for an adjustable stream, and is capable of throwing foggy spray depending on the requirement. The portable agricultural sprayer satisfies the need of the user at the most economical cost. This agricultural spraying machine is having very low manufacturing and maintenance costs. It provides transportability and can be moved anywhere easily. The methodological flowchart of an agriculture spraying machine has shown in Fig. 1.

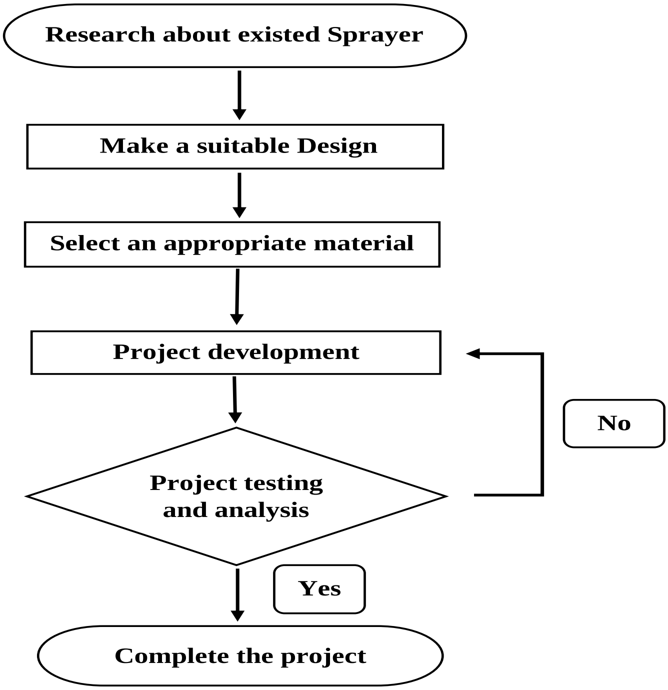


Figure 1: Block diagram of the project

The major components of agricultural spraying machines are sprockets, chains, connecting rods, cranks, pumps, nozzles, wheels, frames, and control valves are used in an agriculture spraying machine. Among them, two major components of crank and knapsack sprayer functions have been described.

Figure 2: (a) Crank mechanism connected with short sprocket and connecting rod, and (b) Knapsack sprayer

The function of the crank is to transfer motion from the prime mover to the connecting rod for further operation. Here the circular disc has eccentricity at which the rotary motion of the crank is converted into the reciprocating/linear movement of the connecting rod. The crank mechanism and knapsack sprayer are shown in Fig. 2. The principle behind the backpack sprayer is the pressure difference created by the hand-operated lever (Shirwal *et al.*, 2014; Raut *et al.*, 2013). It has a single nozzle through which liquid pesticides are forced out in fine droplet form. The capacity of the backpack sprayer is 16 liters which is shown in Fig. 2(b). The components of a backpack sprayer are the tank, piston pump, hose, spraying handle and nozzle. Sprayers convert the pesticides into small droplets, which can be varied by changing the pressure and size of perforation on the nozzle. The smaller size droplet sprays more evenly. The major drawback of a backpack sprayer is that the labor has to carry a nearly 18-19 liters capacity tank on his back, which causes severe back pain and fatigue to the labor. Table 1 summarizes the specifications of a spraying machine.

Table 1: Specifications of a spraying machine

SI No.	Measuring parts	Size (Inch)
01	Main body	41×5 (L×W)
02	Length of nozzle holder	20
03	Height Nozzle head from the main body	19
04	Height of ground to the nozzle head	34
05	Height handle from the main body	15
06	Length of grip	6
07	Height of ground to grip	30
08	Height of leg	12
09	Length from handle to nozzle holder	47
10	Diameter of main wheel	14
11	Diameter of long sprocket	4
12	Diameter of short sprocket	1.5
13	Length of chain	57

2.2 Design calculation of spraying machine

2.2.1 Gear ratio

In this study, a gear sprocket with 48 teeth and a pinion sprocket with 18 teeth were considered. It is known that, the gear ratio = gear sprocket teeth/ pinion sprocket teeth = 48/18 = 2.67:1. If the gear sprocket rotates one time, the pinion sprocket will rotate 2.67 times. When the pinion sprocket completes one rotation, the piston of the knapsack sprayer completes one cycle. Then if the main wheel completes one rotation, the piston will complete a 2.67 cycle. When the piston completes one cycle, that time generating pressure in a knapsack sprayer tank is 4 bar. If the main wheel completes one rotation and the piston completes a 2.67 cycle, the generating pressure is 4 x 2.67=10.68 bar. Therefore, the pressure of 10.68 bar is the maximum pressure of knapsack sprayer and 1–4 bar is the working pressure of knapsack sprayer.

2.2.2 Flow rate of nozzles

The backpack sprayer capacity is 16 litter, and the generating pressure is 0.3 - 0.4 MPa. To facilitate the backpack sprayer, the ATR-60 nozzle is used in this study. For 5 bar pressure, discharge for the nozzle is 0.75 L/min. For 1 bar pressure, discharge for the nozzle is 0.75/5 = 0.15 L/min. Now the average pressure has taken 4 bar. For 4 bar pressure, the discharge will be = 0.15 x 4 = 0.6 L/min. Then it is considered to be used two ATR-60 nozzles. Discharge of two nozzles will be = 0.6 x 2 = 1.2 L/min. So, the discharge of the sprayer machine is = 1.2 L/min. The capacity of the backpack sprayer is 16 litter. So, the time required for two nozzles to spray is 16 litter =16/1.2 = 13.33 min.

2.3 3D model of a sprayer machine

In this study, the basic structural design is done by the SolidWorks software. Fig. 3 shows the schematic 2D and 3D views of the sprayer machine. It can be seen from Fig. 3 that there are three different views which are the isometric view (Part-A1), top view (Part-A2), front view (Part-B1), and side view (Part-B2). The reservoir tank contains pesticides and also the reciprocating pump. The pump outlet is connected to the spraying nozzle through a flexible pipe. The final 3D-designed model is shown in Figure. 4.

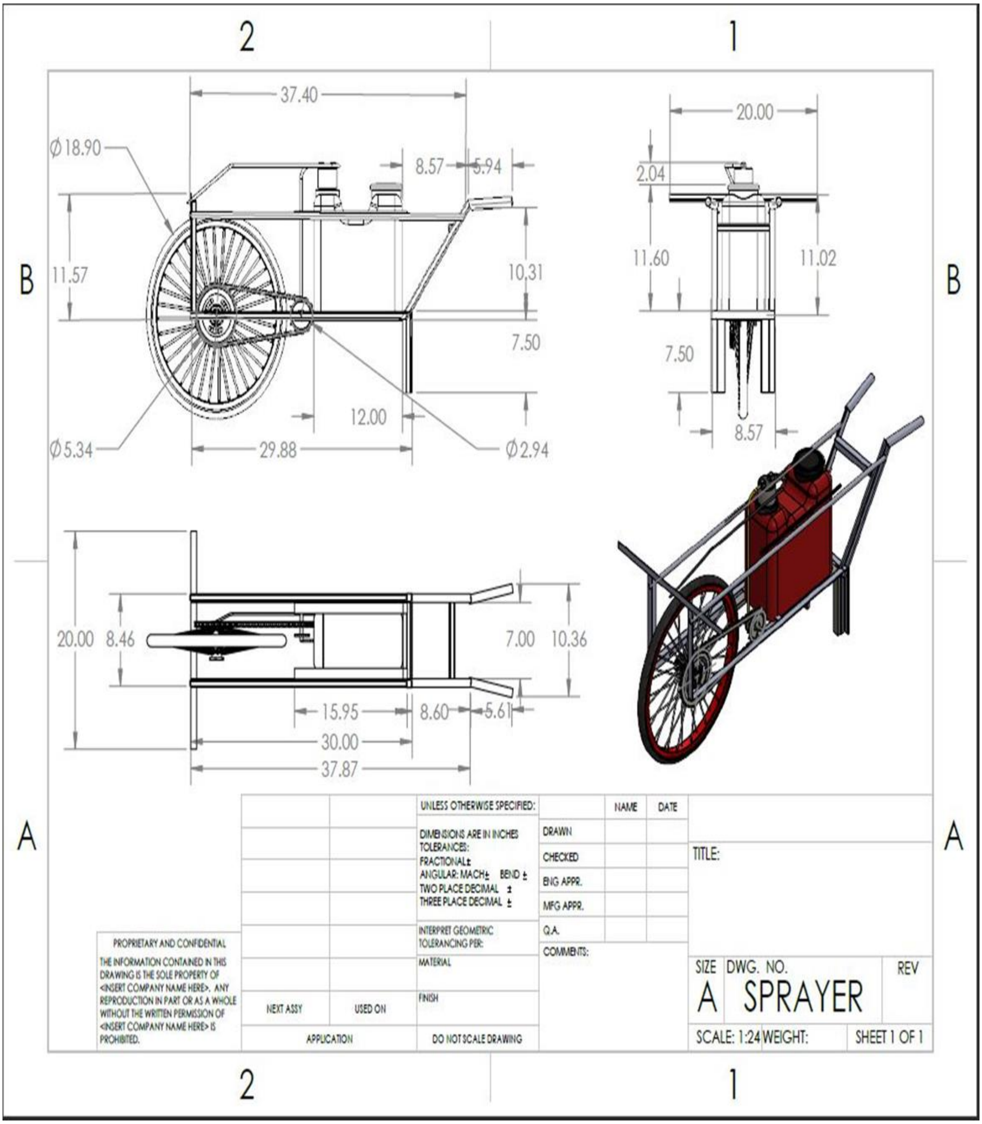


Figure. 3: Schematic view of 2D and 3D design of a sprayer machine

(a) Right side v (b) Front view (c) Top view

Figure 4: 3D CAD model of a sprayer machine

2.4 Experimental test

Figure. 5 shows the working flow diagram of a designed sprayer machine. As can be seen from the flow diagram, the operator grabs the handle and pushes the cycle forward as the cycle moves forward; the wheel rotates. When the wheel rotates, then the gear sprocket mounted on the wheel is also rotated at the same speed. The chain drive transfers the motion of the gear sprocket to the pinion sprocket. The pinion sprocket and crank are mounted on either side of the same shaft, and the rotary motion of the shaft is converted into the reciprocating motion with the help of the crank and connecting rod mechanism. The connecting rod is also connected to the lever and then the lever oscillates at the fulcrum. The piston connected at the fulcrum produce reciprocating motion in the cylinder and the required pressure is achieved.

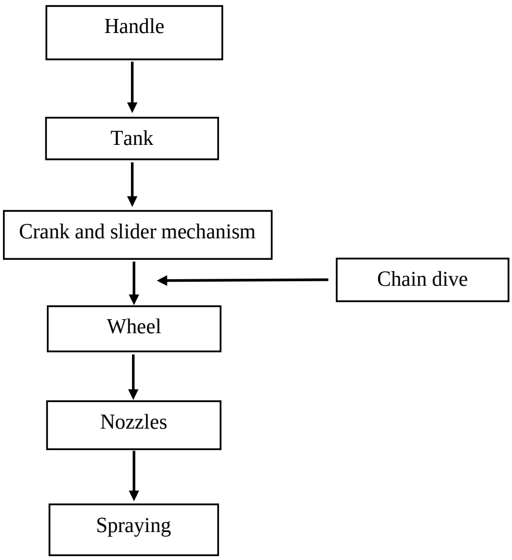


Figure 5: Work flowchart for developing equipment

The pesticide from the tank sucks in the cylinder and the piston forced the pesticide to the nozzle through the pipe; the number of nozzles is connected to spraying the pesticide. Farmers can adjust the pressure, which is required for spraying with the help of a special arrangement to change the length of a crank by providing a slot on the crank. Providing some adjustment at the joint of the connecting rod and lever-free rotation of the crank or neutral position can be achieved. Using these adjustments, pumping is stopped, and the wheel rotates freely when farmers need not spray pesticides.

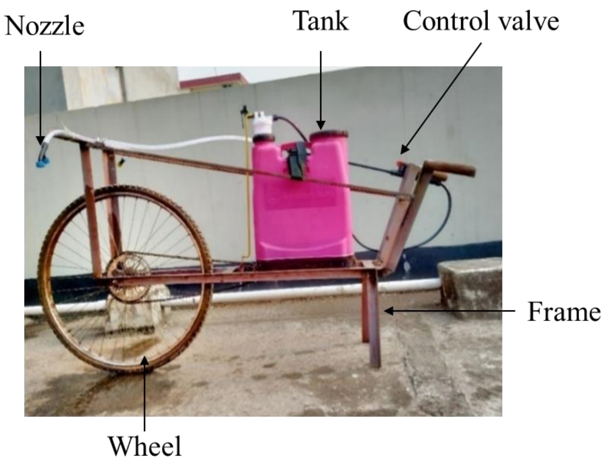
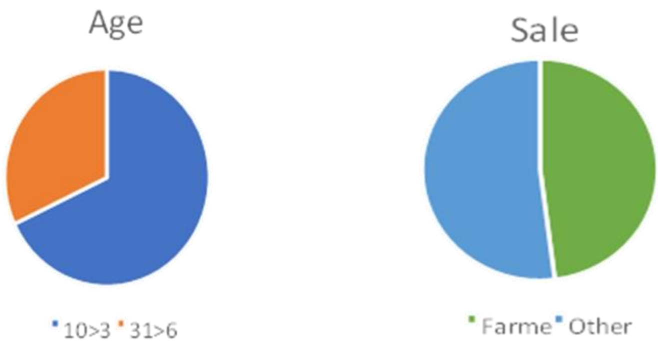


Figure 6: Working model of an agricultural spraying machine

According to Fig. 5, the spraying machine was assembled. The experimental procedures are as follows: (1) it is a manually operated spray pump that has a simple structure. It comprises a single wheel, piston pump, bearings, nozzle, shafts, trolley, pipe, crankshaft, handle chain drive, etc. (2) There is trolley like structure containing a pump on it and space for fitting several nozzles at a certain height as per requirement. (3) The rear wheels are connected by a shaft. Bearings are provided on both sides for smooth motion. (4) The wheel is connected to the crankshaft by chain drive. The crankshaft is then connected to a piston pump with a connecting rod. (5) The piston pump is placed middle of the frame, which has reciprocating movement. (5) The nozzle is mounted on the upper side of the tank. The nozzle having flexible pipe which is moved or turn any direction. Fig. 6 shows the final fabricated model of a sprayer machine.

3. Results and Discussion

The product had been given to the farmer for testing purposes. They filled the tank with pesticides and clean water and moved the whole unit of pesticides onto the pepper plant. It is found that the sprayer machine was easy to use and suitable to run to them and it's a more usable sprayer than before they used one. The feedback analyses have environmental implications for the farmers for questions 1 and 2, as shown in Fig. 7. Two questions were, (1) are you get back pain while operating the sprayer machine? And (2) is it easy to operate and economical for the farmers if you purchase? From questionnaire 1, questions were answered by most of the young and youth people and farmers. The scale for this question is 10-30 (17) and 31-60 (8). From questionnaire 1, the value of farmer and others that have answered this question is quite balanced, which is a farmer (12) and others (13). Based on the question in section B, 25 persons have answered all the questions, as shown in Fig. 8. Some of them have answered YES, and some of them have answered NO because of their own opinion. It was found that many of the respondents pick YES for all the questions. Some respondents give us suggestions and ideas to improve the product. The common suggestions were for the product to be capable of using in all types of farms and gardens and making a better handling method. The performance of the equipment will increase when it is operating on a smooth surface or less uneven surface. Also it will be more effective when it is used on the crop shaving nearly similar height and having the less space between two crops.



a) Section A, Question 1 (b) Section A, Question 2

Figure 7: (a) Section A, Question 1, and (b) Section A, Question 2

Comparison between the existing machineries and present machine shows that the single wheel operated machine can work efficiently regarding covering area, time and cost of spraying process. Also, it seems economical. During testing, the speed of vehicle varies continuously; it's because of varying track resistance. Further, it is assumed that the spraying would be stopped partially, but the pressure generated in spraying pump continues to spray the pesticide because the pressure developed in the pump suffices to spray for few minutes.

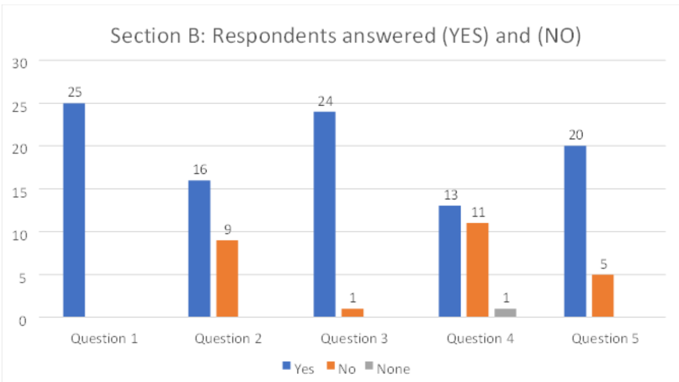


Figure 8: Section B, Respondent Answered Yes or NO

As the vehicle moves in forward direction, slider crank mechanism activates and due to it pressure will be generated in the tank and pesticide will be sprayed out from the nozzle. This machine will be operated by pushing the vehicle in forward direction; therefore, no harm effect will occur to human health. Also, it covers larger area in less time so lots of time will be saved with this and also labor cost will reduce and money saved. As the nozzle distance increases, the distance travelled by the droplet reduces. In order to reach a more distant, the pressure applied on the footrest must be more. The nozzle with a suitable design is to be selected. It finds more usefulness for an adult person with a weight of more than 50 kg.

Table 2: Performance of developed sprayer

SI No.	Parameter	Performance
01	Construction	Light and compact
02	Weight	30 kg
03	Efficiency	High
04	Cost	Low
05	Maintenance	Low
06	Ground clearance	High
07	Versatility	More

As the comparison between the traditional sprayer and developed sprayer, it covers the maximum area of crop. Table 2 shows the comparison between the traditional sprayer and developed sprayer. Thus, the sprayer is a simple constriction because of this changed design; it makes human safety and then continuous running and spraying is possible. There is no vibration occurs while this sprayer is running, so it makes even spray towards the crops. Based on the result, the sprayer has maintained an average nozzle pressure of 2 bars during both the field and laboratory tests at an average speed of 1.4 km/hr. According to (Shivaraja *et al.*, 2021; Thanuj *et al.*, 2015), the average nozzles discharge rate variation along travel distance reduced and attained an optimum discharge rate the nozzles 30 m distance. Proper adjustment facility in the model concerning crop helps to avoid excessive use of pesticides, resulting in less pollution. Imported hollow cone nozzles should be used in the field for better performance. Fig. 9 shows the time comparison between traditional and developed sprayers.

For test-1: The sprayer machine was tested on 08-02-2022 at agricultural land, and performing the agricultural spray is noted. It was found that the farm spray for 1 meter/min sparing area is 1900×10^3 mm^2, and then some mild vibration is observed in the main wheel during spraying time. Thus, the test result was desirable, and the agricultural spray was adequate.

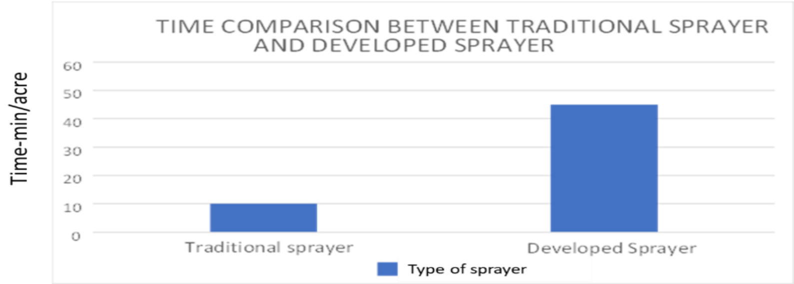


Figure 9: Time comparison between traditional and developed products.

For test-2: to resolved the vibration problem, the two square bars of steel from the nozzle head to the handle were connected of the main wheel. Then the sprayer machine was tested again on 10-02-

2022 on agricultural land, and the performance of the agricultural spray was noted. This time it was found that the agricultural spray for 1 meter/min sparing area is 2100×10^3 mm². At that time, the result of the test conducted was desirable and the agricultural spray was properly. According to the survey and research, the following are the parameters which have been studied following results are achieved, as shown in Table 3.

Table 3: Comparison between the traditional sprayer and developed sprayer

SI No.	Parameter	Traditional sprayer	Developed sprayer
01	Nozzle	1	2
02	Time	2 hrs./acre	35 min/acre
03	Covered area	Minimum	Maximum
04	Effort	More	Less
05	Operator fatigue	More	Less
06	Cost	Low	Medium
07	To operate	Difficult	Easy

This study focused on gardeners and farmers spraying liquid like pesticides, herbicides, and water on their plants. There are so many ways how to spray their plant, but the most common is using a manual plastic knapsack sprayer. After finishing the product testing, enough expectation has been found through this product. First of all, try to reduce the time it takes to spray the herbicide by almost three times faster than the manual knapsack sprayer. Next, this sprayer has been allowed to add more efficiency to spraying with this pair of nozzles on the wing side. It is more efficient because when the product is moving forward, it will generate pressure on the pump, and the herbicide will flow to both sides of nozzles and sprinkle to plants. The last objective has been achieved is farmers can spray more comfortably than before.

4. Conclusion

The proposed design can help farmers and agricultural workers spray pesticides in their farms and gardens since it is more ergonomic to use and handle. This new sprayer machine can help them to reduce their time to spray because they have two nozzles on the right and left sides of the sprayer. This designed sprayer machine will give many benefits to farmers who will use it. Moreover it will contribute to good results and productivity in farming industries. It consumes less time and saves money as compared with conventional spraying. This machine does not require any fuel or power, so maintenance is less. This model removes the problem of back pain, vibrations, and noise. This sprayer can use for multiple crops. The model has provided multiple nozzles, which have continuous spray over crop, and this process takes less time than other sprayers for spaying. However, there are some limitations, like it will be difficult to work in irregular, uneven and wet farmlands. The gear ratio has been used in this study was 1:2.67, which could be varied according to the need and design to get a variety of performances in the sprayer. Also, a number of nozzles could be used. On top of that, a higher capacity bag pack sprayer could be used for work reliably under different working conditions.

Author’s contribution

The study conceptualization, methodology, and data analysis were performed by M. Rakibuzzaman, A. Amin; A. Islam and M. R. Khan performed the draft preparation; M. R. Khan performed the validation and M. Rakibuzzaman reviewed and editing the paper. Also, M. S. Rahman advised on the project work.

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Conflict of interest

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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