Design and implementation of a petrol engine-driven boom sprayer for precision agriculture in field crop management

Md Rejaul Karim[1], Muhammad Arshadul Hoque[1], Muhammad Rashed Al Mamun[2,3*], Rifa Tanjim[3]

(1. Farm Machinery and Post-Harvest Process Engineering Division, Bangladesh Agricultural Research Institute, Gazipur-1701, Bangladesh;
2. Faculty of Agriculture, Kyushu University, Fukuoka 819-0395, Japan;
3. Department of Farm Power and Machinery, Faculty of Agricultural Engineering and Technology, Sylhet Agricultural University, Sylhet-3100, Bangladesh)

Abstract: The development of a petrol engine-driven boom sprayer involved meticulous design and fabrication processes at the Regional Agricultural Research Station (RARS) in Jashore. Gradual refinements occurred 2020-2023 at the Farm Machinery and Postharvest Process Engineering (FMPE) Division of the Bangladesh Agricultural Research Institute (BARI) in Gazipur. Notable improvements included integrating a precision spray pump, replacing the conventional front wheel-based pumping mechanism with a reciprocating action assembly. Appropriate laboratory and field testing adhered to standardized protocols, with controlled dry runs conducted over a 12-meter path at a consistent forward velocity of 2.6 k h^{-1}. Performance evaluations revealed substantial achievements: an effective swath width of 2.9 meters, theoretical field capacity of 0.8 ha h^{-1}, effective field capacity of 0.7 ha h^{-1}, and an operational efficiency rating of 93%. These results significantly surpassed comparative assessments against both manually operated electric rechargeable knapsack and manual knapsack sprayers. Successive field trials, spanning the 2022-2023 growing seasons, employed a randomized complete block design (RCBD) framework, featuring four treatment regimens (T_1=Boom Sprayer, T_2=Electric Knapsack Sprayer, T_3=Manual Knapsack Sprayer, T_4=Control) with three replicates each. Precision full cone nozzles were utilized for experimental applications of the herbicide "Affinity 50.75 WP" on Barley (BARI Barley 6 variety) crops. While no statistically significant deviations in yield outcomes were observed, a marked reduction in application time and pronounced suppression of weed proliferation underscored the superior efficacy of the engineered boom sprayer system.

Keywords: boom sprayer, crop spraying, herbicide application, farm equipment efficiency

Citation: Karim, M. R., Hoque, M. A., Al Mamun, M. R., and Tanjim. R. 2024. Design and implementation of a petrol engine-driven boom sprayer for precision agriculture in field crop management. Agricultural Engineering International: CIGR Journal, 24 (4):91-104.

1 Introduction

Bangladesh is an agricultural country with a gross cropped area is about 15.595 M ha and a net cropped area is 8.02 M ha (Bangladesh Bureau of Statistics [BBS], 2019). The country has 2.231 million hectares for single crops, 3.966 million hectares for double crops, and 1.788 million hectares for triple crops. Currently, 40.2% of the population is engaged in agriculture, but there has been a notable shift of

Received date: 2024-04-26 **Accepted date:** 2024-10-10

***Corresponding author: Muhammad Rashed Al Mamun,** Ph.D., Specially Appointed Professor, Faculty of Agriculture, Kyushu University, Fukuoka 819-0395, Japan. Email: rashed.fpm@sau.ac.bd. Tel: + 81-070-9116-2903, Fax: +81-92-802-4632.

agricultural laborers to other sectors in recent decades. Therefore, the scarcity of agricultural labor is increasing gradually. Based on current projections, there is an anticipated decline in the agricultural labor force, with estimations suggesting a reduction to 30% by the year 2025 and further down to 20% by 2030 if present trends persist (BBS, 2017). The agricultural sector serves as the cornerstone of Bangladesh's economy. Significant advancements, including the integration of modern technology, mechanization for efficiency, chemical applications for pest control and fertilization, government initiatives, and specialized strategies, have collectively contributed to a substantial increase in crop production (Agriculture Sector Review [ASR], 2006). Advancements in agriculture, including technology and mechanization, have addressed labor shortages for crop production. However, increased production brings challenges in crop protection and management. Protecting crops from pests is essential, but losses continue to rise. According to research findings, the application of pesticides enables farmers to mitigate losses in fruits, vegetables, and cereals by approximately 78%, 54%, and 32%, respectively (Tudi et al., 2021). In the agricultural sector, farmers engage in various tasks such as weeding, reaping, sowing, and spraying. Among the tasks conducted in agricultural fields, spraying stands out as a crucial operation typically undertaken by farmers to safeguard their cultivated crops against pests, insects, fungi, and diseases. This involves the application of a range of insecticides, pesticides, fungicides, and nutrients to provide protection to crops (Krishna et al., 2017).

A spraying apparatus holds significant importance in ensuring the accurate administration of pesticides and safeguarding crops from potential damage caused by pest infestations. Various types of sprayers and weed eaters are presently accessible, encompassing manually operated, animal-drawn, tractor-mounted, and self-propelled iterations (Ambaliya et al., 2022). To attain the best results, it's crucial to select the appropriate sprayer for the crop and application (Jalu et al., 2023). It can significantly contribute to pest management efforts and markedly enhance food production while also preserving substantial crop yields. Crop productivity is compromised not solely by pest and disease infestations but also by the presence of weeds. Chemical control methods are widely utilized for managing various insects, weeds, and diseases, although alternative approaches exist for controlling pest, disease, and weed infestations (Rabbani et al., 2020). Spraying stands out as a highly effective and efficient method for applying precise volumes of spray liquid to safeguard crops against pest, disease, and weed infestations. Farmers frequently use lever knapsack sprayers, which cause discomfort in the head, neck, clavicle, and shoulder regions due to their awkward posture during operation (Mishra et al., 2023). Research estimates that it is between 50% and 80% of applied pesticides are lost due to inadequate spray equipment and improper application techniques (Khan et al., 1997). Battery-operated sprayers present operational limitations including nozzle clogging, substandard spray quality, increased human exertion, reduced field capacity, uncertainty regarding grid power availability, and battery deep discharge, among other factors. During the spraying process, farmers manually manipulate the spray nozzle head, leading to uneven pesticide application, thus diminishing operational efficiency and economic viability (Kakade et al., 2018).

The irregular distribution of pesticides can lead to phytotoxicity (caused by overdosing) and pest resistance (caused by underdosing). Effective performance of manual operations relies significantly on the interaction between humans and machinery (Khan et al., 1997). Ensuring a consistent walking speed and maintaining an optimal distance between the nozzle and plant tops are crucial for achieving uniform spray material distribution. Any fluctuations in walking speed or the height of the sprayer nozzle from plant tops can lead to uneven distribution of the spray material.

In traditional practices, fluid is transported to various targets using manually operated low and high-volume hydraulic sprayers, as well as power-operated hydraulic sprayers equipped with extended booms, lances, or spray guns. Recently, different types of battery-powered manually operated knapsack sprayers are found in the markets which are also used in crop fields for plant protection. However, this approach typically demands greater time and labor. Achieving uniform and effective pesticide distribution throughout the plants can be challenging using conventional spraying methods as well (Mittal et al., 1996). While this approach delivers effective pest control, it necessitates a substantial volume of liquid per plant, along with considerable time and labor inputs. Additionally, drip losses tend to be elevated. In light of environmental conservation efforts aimed at minimizing pesticide-related pollution and optimizing resource utilization, it is imperative to explore alternative spraying methods. Though there are different types of spray machines used in the field most of those are not completely user-friendly, cheap, and hazardous to carry in a knapsack including 16–20-litre spray liquid. That is why the recommended quantity of spray liquid is not applied during spray and the desired result does not come in most cases.

The engine-operated petrol engine operated sprayer is a better option due to its medium cost and small size implying better maneuverability in the small land holding. Self-propelled walking-type sprayers can fill the mechanization gap to do spraying operations at a faster rate. This shows that there is an urgent need to introduce mechanical sprayers in Bangladesh. The engine-operated self-propelled sprayer should be easily maneuverable and less expensive for farmers or the best source of power spraying operation. Bangladeshi farmers are increasingly embracing the current trend of row cropping practices. The demand for the development of lightweight, engine-operated sprayers, particularly self-propelled vehicle types, powered by petrol, is becoming increasingly evident. Considering this, a user-friendly and easy-operate spray machine is needed through which effective ways of using pesticides could be adopted. In order to attain the objective of precise spraying, it is imperative to develop a user-friendly petrol engine-operated boom sprayer tailored for upland field crops. Hence, the focus of this research endeavor was to design and fabricate a petrol engine-operated boom sprayer specifically intended for upland field crops. The primary aim was to ensure accurate application of herbicides and insecticides while concurrently minimizing spray time consumption.

2 Materials and methods

Designed in 2020-21 (Figure 1), a row-crop boom sprayer underwent enhancements in 2021-2022 (Figure 2) and 2022-2023 (Figure 3). Fabricated at RARS Jashore and improved at FMPE Division, BARI, Gazipur, the machine prioritized adjustability, lightness, capacity, and local manufacturability. Utilizing local materials, including MS components and rubber parts, it featured a spray pump and two nozzle types.

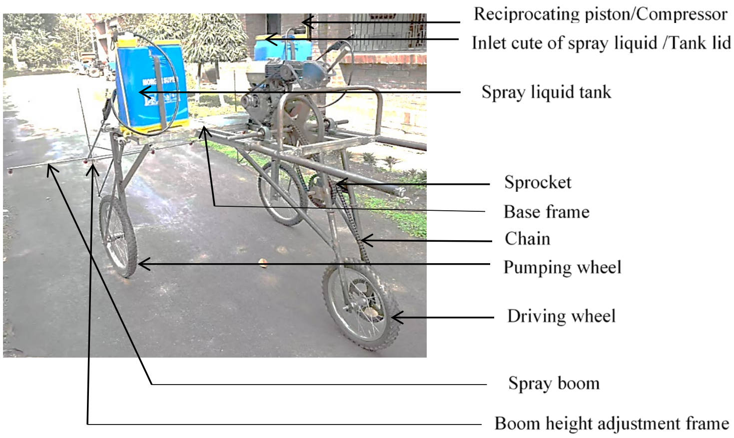


Figure 1 The major components and operational elements of the boom sprayer (Initial Prototype created between 2020 and 2021)

Figure 2 The primary components and operational elements of the boom sprayer (Developed during 2021-2022)

Figure 3 The major components and operational aspects improved in the boom sprayer (Developed during 2022-2023)

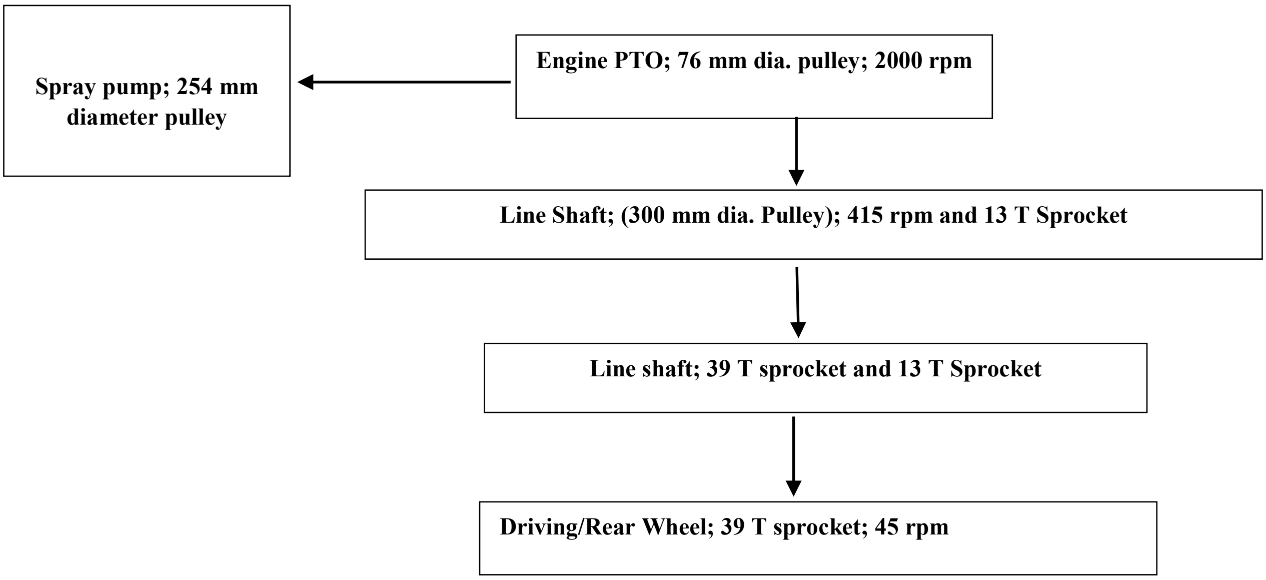


Figure 4 The power transfer mechanism of the boom sprayer

2.1 Power transmission system

The equipment is propelled by a 6.5 horsepower petrol engine, which propels the rear wheel via a power transmission mechanism as shown in Figure 4. The power is transferred from the engine to the rear wheel via a belt, pulley, chain, and sprocket arrangement. As the rear wheel rotates, it in turn drives the front wheels, propelling the machine forward. Simultaneously, the front wheels are responsible for transmitting power to reciprocate the piston or compressor through a reciprocating rod, facilitating the discharge of spray chemicals through the nozzles.

The technical specifications of the boom sprayer developed in 2019-2020 and improved in 2020-2021 have been mentioned in Table 1.

Table1 Technical specifications of the boom sprayer in (2019-2020) and (2020-2021)

Sl. No.	Particulars	Specifications (2019-2020)	Specifications (2020-2021) and (2021-2022)
1	Engine	Petrol; 4 hp.; 4 strokes	Petrol; 6.5 hp.; 4 strokes
2	Length × Width	135 cm × 142 cm	120 cm × 151cm
3	Ground clearance	90 cm	90 cm
4	PTO rpm (Avg.)	2000	2000
5	Line shaft rpm	416	415
6	Power wheel (Rear wheel) rpm	46	46
7	Power wheel (Rear wheel) perimeter	103 cm	110 cm
8	Forward speed	2.8 km h^{-1} (without slip)	2.9 km h^{-1} (without sleep); 2.56-2.67 km h^{-1} (with sleep)
9	Nozzle types	Hollow cone and flat fan	Hollow cone and flat fan
10	Discharge of one hollow cone nozzle	911 mL min^{-1}	764 mL min^{-1}
11	Discharge of one flat fan nozzle	760 mL min^{-1}	Was not tested/used
12	Width of one boom (3 nozzle boom)	100 cm	100 cm
13	Nozzle spacing in boom	50 cm apart	50 cm apart
14	No. of boom	2 Nos. in 2 parts	2 Nos. in 2 parts
15	No. of nozzles	3 Nozzles in every boom; a total of 3 +3 = 6 nozzles in 2 individual booms which attached in one frame	3 Nozzles in every boom; total 3 +3 = 6 nozzles in 2 individual booms which attached in two adjustable frames
16	Type of pumping/compressing device	Reciprocating piston/compressor	Engine-operated spray pump
17	Strokes of reciprocating piston	33 Nos./min	N/A because the spray pump had been used
18	Type of the machine	self-propelled & walking type	self-propelled & walking type
19	Theoretical width of coverage	300 cm	300 cm
20	Fuel consumption	650-700 mL h^{-1}	700-750 mL h^{-1}
21	Tank capacity	16 + 16 = 32 L (2 Nos. of 16 L volume tank attached with 2 knapsack sprayer of the machine)	75 L
22	Boom height adjustment system	Re-adjustable	Re-adjustable
23	Line/row spacing adjustment system	Re-adjustable for 20 cm, 30 cm and 60 cm line-to-line distance of crops	Re-adjustable for 20 cm, 30 cm and 60 cm line-to-line distance of crops

2.2 Working principle of the boom sprayer

To initiate the machine, start the engine with the main lever in the disengaged position. Shift the main lever and forward gear lever to the engaged position to activate power transmission, propelling the machine forward. At the same time, the spray liquid from the reservoir flows into the pump via the inlet conduit. Open the gate valve of the delivery pipe, initiate spray liquid discharge through the pipe and spray lance, producing spray mist from the six nozzles on the boom.

2.3 Laboratory test, data collection and processing

Following the improvements, the sprayer underwent testing in laboratory conditions. Data was collected and processed for manual knapsack sprayer, electric knapsack sprayer, and boom sprayer. The lab test involved a dry run of the machine over a 12-meter distance, from which the forward speed was calculated. Different performance parameters, such as the effective coverage width, theoretical field capacity, effective field capacity, and efficiency, were also computed. The subsequent sections provide detailed descriptions of the major parts and functional components of the sprayer.

2.4 Travelling speed

Since the sprayer was powered by a petrol engine, its speed fluctuated in accordance with the engine's revolutions per minute (rpm). The average of three readings was obtained to determine the machine's traveling speed in kilometers per hour (km h^{-1}). The velocity of the machine was computed using Equation 1:

$$S = \frac{d}{t} \tag{1}$$

where, S represents the speed in kilometers per hour (km h^{-1}), d denotes the distance traveled in kilometers (km), and t stands for the time taken in hours (h).

2.5 Width of operation

The width of the spraying operation was randomly sampled at various locations and measured relative to the mean value.

2.6 Theoretical field capacity

Theoretical field capacity was determined using Equation 2 (Kepner and Bainer, 1978; Hunt, 1978).

$$C_t = \frac{w \times s}{c} \tag{2}$$

Where, C_t is theoretical field capacity (ha h^{-1}), W is spraying width of the boom (m), S is speed (km h^{-1}) and C is constant, 10.

2.7 Effective field capacity

The time allocated to actual work and time lost due to ancillary activities such as turning and refilling the spray tank were factored into the calculation of effective field capacity. The stopwatch was utilized to measure the duration of both operational and non-operational intervals. Excluding the time spent refueling was deliberate, as pre-filling the tank before the test often eliminates the need for refueling during extensive field operations. Additionally, time spent on troubleshooting machine issues or addressing nozzle problems was omitted from consideration due to its variable nature and potential to artificially deflate effective field capacity figures. The formula employed to compute the sprayer's effective field capacity is as follows Equation 3 (Kepner and Bainer, 1978; Hunt, 1978). The effective field capacity serves as a measure of the area effectively covered within a given unit of time.

$$C = \frac{A}{T} \tag{3}$$

Where, C is field capacity (ha h^{-1}), A is total area covered by the sprayer (ha) and T is total time (h).

2.8 Field efficiency

It represents the ratio of the effective field capacity to the theoretical field capacity (Kepner and Bainer, 1978; Hunt, 1978). The field efficiency of the sprayer was determined using the subsequent equation.

$$e = \frac{c}{ct} \times 100 \tag{4}$$

Where, e is the field efficiency (%).

2.9 Application rate

The application rate was established using the subsequent Equation 5 (Issa et al., 2020).

$$Application\ rate\left(\frac{L}{m^2}\right) = \frac{Volume\ collected\ (L) \times Time(min)}{Time\ (min) \times Area\ of\ test(m^2)} \tag{5}$$

2.10 Measurement of missing and overlapped spraying area

The spraying area coverage data was documented using a white sheet as the backdrop for spraying. A mixture of blue color and water was applied onto the paper during a single pass to delineate the sprayed region. Subsequently, the colored area was quantified to assess the efficacy of the power boom sprayer. The colored region indicates the sprayed area, while the white sections signify areas that were missed or left untreated, and the darker regions represent overlapping coverage. The procedural steps are illustrated in Figure 5.

2.11 Measurement of missing area percentage

After measuring the blue and dark blue colored regions, the uncolored white space was designated as the omitted area. The calculation of the omitted area was performed using the following formula (Rabbani et al., 2020)

$$Missing\ area\ (\%) = \frac{white\ area(cm^2)}{Total\ area(cm^2)} \times 100 \quad (6)$$

$$Overlapping\ area\ (\%) = \frac{Dark\ blue\ area(cm^2)}{Total\ area(cm^2)} \times 100 \quad (7)$$

2.12 Image analysis of spray drift/pattern

The determination of droplet diameter involved mixing ink and water in a ratio of 30 ml of ink to 1000 ml of water, which was subsequently sprayed onto water-sensitive paper (WSP) (refer to Figure 7a). Immediately after the sprayer passed over the WSP, an image of the result was captured. The WSP utilized in this process was obtained from Syngenta, a well-known global supplier of pesticides that operates in Bangladesh as well. To see the droplet attributes the image was collected using this paper maintaining the same focal length: 3.70 mm, ISO: 40, resulation: 4128×3096 and aperture: F1.9. To keep these two criteria constants, an image-collecting small-size device (Figure 7c) was developed as per design where a camera (Figure 6 b) was fixed. After taking the image, it was processed for analysis and the spray drip results were analyzed with an image analytical software "ImageJ software" to determine the spray drift pattern.

Figure 5 Spraying on white paper

(a) Water sensitive paper (b) Camera (c) Image collection device

Figure 6 Data acquisition components

2.13 Experimental design and field test of the boom sprayer

The experimental setup followed a randomized complete block design (RCBD) comprising four treatments: T_1=Boom Sprayer, T_2=Electric Knapsack Sprayer, T_3=Manual Knapsack Sprayer, and T_4=Control, each replicated three times. Full cone nozzles were employed for the application of the herbicide "Affinity 50.75 WP." Barley crops, specifically the BARI Barley 6 variety, were utilized in the study. The seed was sown in line (spacing 20 cm) on 26 December 2021 and the Affinity was sprayed following recommended doses on 23 January 2022. The unit plot area was 2.5 m× 6.5 m and the number of weeds was counted on 24 days after herbicide Spraying.

Full cone nozzles were used which was particularly recommended for herbicide spraying. Fertilizer management, irrigation, and other intercultural practices adhered to recommended doses and schedules. The data relevant to yield and yield attributing characters were collected and the data were analyzed through statistical software "R Studio 4.0.3". For testing the normality of data, the Duncan Test (DMRT) and analysis of variance (ANOVA) was done.

(a) Spray pattern of full cone nozzle (b) images of full cone nozzles

Figure 7 Full cone nozzle and spray pattern

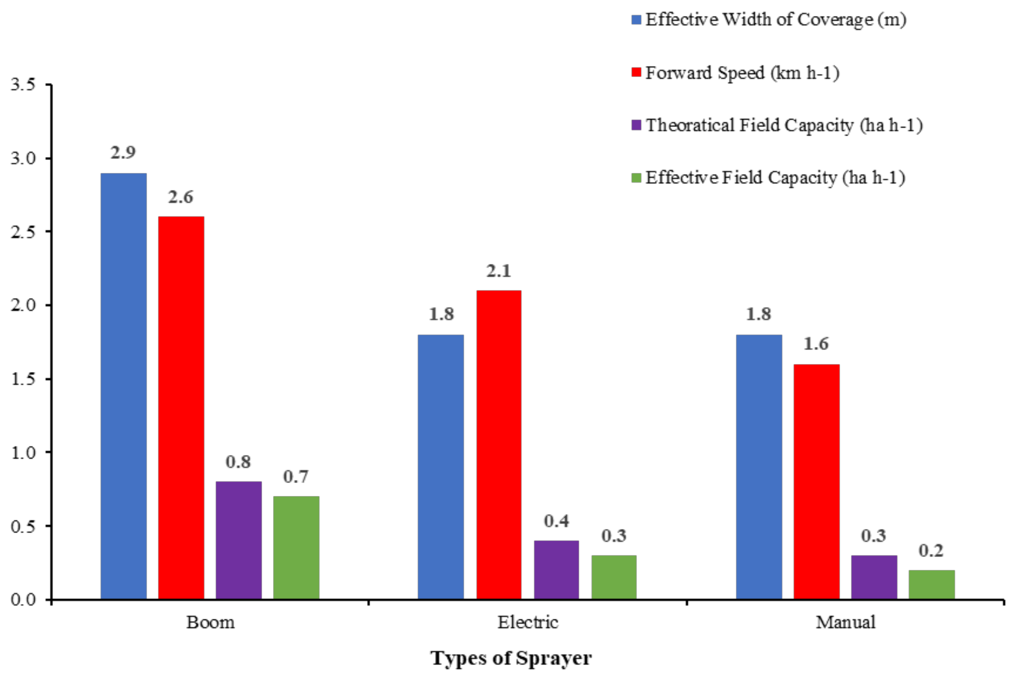
3 Results and discussion

In 2021 (Figure 8a), the improved boom sprayer demonstrated superior performance with a 2.9 m effective width of coverage, 2.6 km h^{-1} forward speed, and higher theoretical (0.8 ha h^{-1}) and effective (0.7 ha h^{-1}) field capacities compared to the electric and manual knapsack sprayers, which showed similar results at 1.8 m coverage.

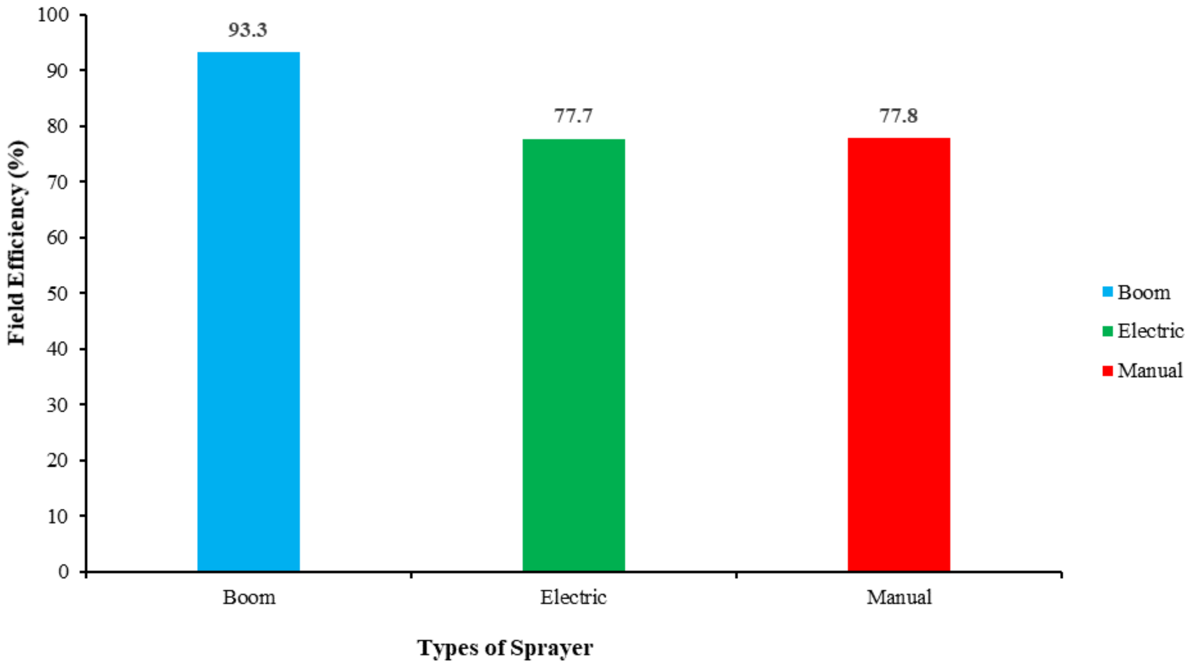
From Figure 8(b) it was found that the field efficiency was highest (93%) for the power boom sprayer whereas the efficiency of manual knapsack and electric knapsack sprayer was 78% respectively.

3.1 Measurement of missing and overlapped spraying area percentage

The missing and overlapped spraying area percentage was calculated and found that the Overlapping percentage of boom sprayer was 0.97% whereas the missing area percentage was 1.3%.



(a) The effective width of coverage, forward speed, theoretical field capacity and effective field capacity of three types of sprayers



(b) The field efficiency of three types of sprayers The field efficiency of three types of sprayers

Figure 8 The comparative performance of sprayers

3.2 Application rate

The application rate was determined by collecting the spray liquid in plastic bottles from three different types of sprayers equipped with hollow cone nozzles attached to the spray lance or boom. It was measured after collection with a measuring cylinder and the result is shown in Figure 9. The highest application rate was found to be 820 L ha^{-1} for the boom sprayer while the lowest rate was found to be 694 L ha^{-1}for the manual knapsack sprayer. It was found to be 716 L ha^{-1} for an electric sprayer (Figure 11).

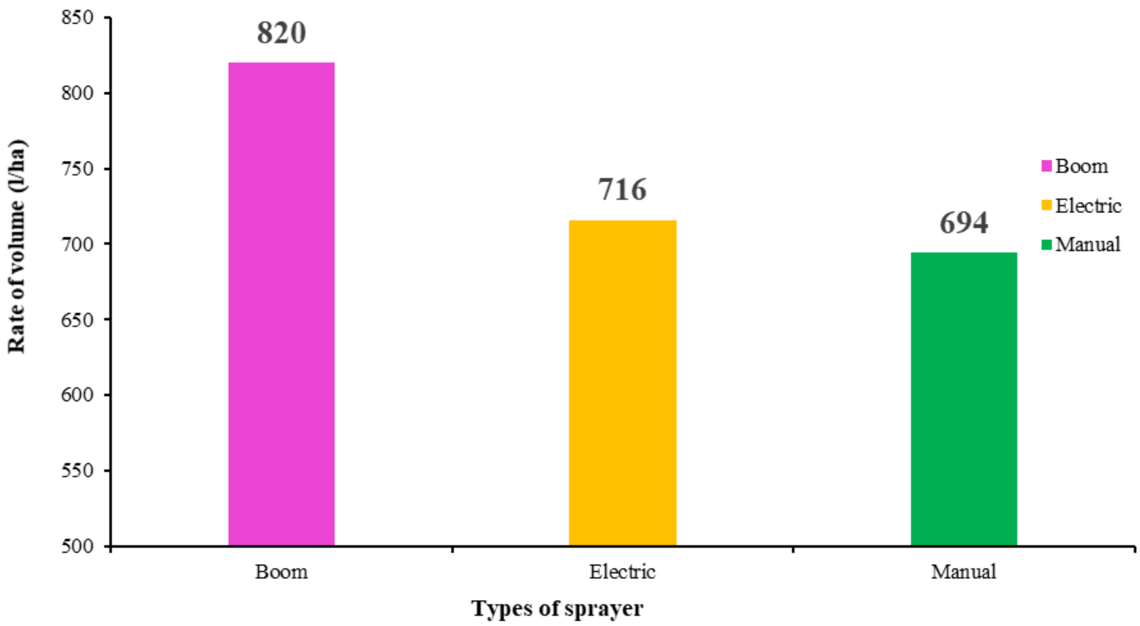
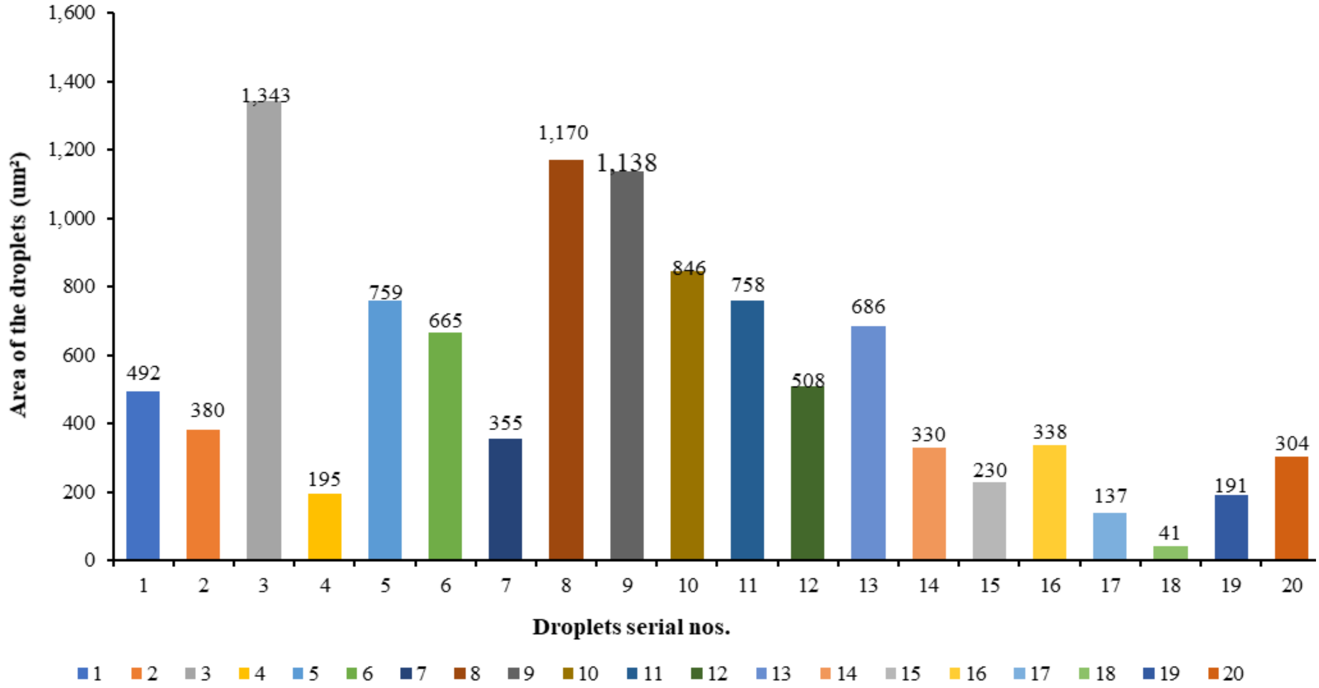


Figure 9 The application rate of spray liquid volume of three types of sprayers

3.3 Spray drift distribution pattern

The spray drift distribution pattern of the boom sprayer, electric sprayer and manual knapsack sprayer were shown in Figure 10-12 respectively where sample counts were 20 droplets for every type of sprayer. The bar graphs in Figures 11a, 12 a, and 13a visualized the droplets sizes of each data set (20 droplets collected from each sprayer).



(a) Boom sprayer droplets distribution pattern

(b) image in WSP (c) processed image

Figure 10 Image based distribution patterns of spray drifts of boom sprayer

The coefficient of variation (CV) for the given data set of boom sprayer, electric sprayer and manual knapsack sprayer were found to be of 42.87%, 72.16% and 65.60%, respectively where the degree of uniformity in the data set, with a lower percentage were indicating higher uniformity. The obtained results revealed that the uniformity of droplet size distribution pattern of boom sprayer was better than electric sprayer and manual knapsack sprayer. The result also demonstrated that the manual knapsack sprayer outperformed the electric knapsack sprayer.

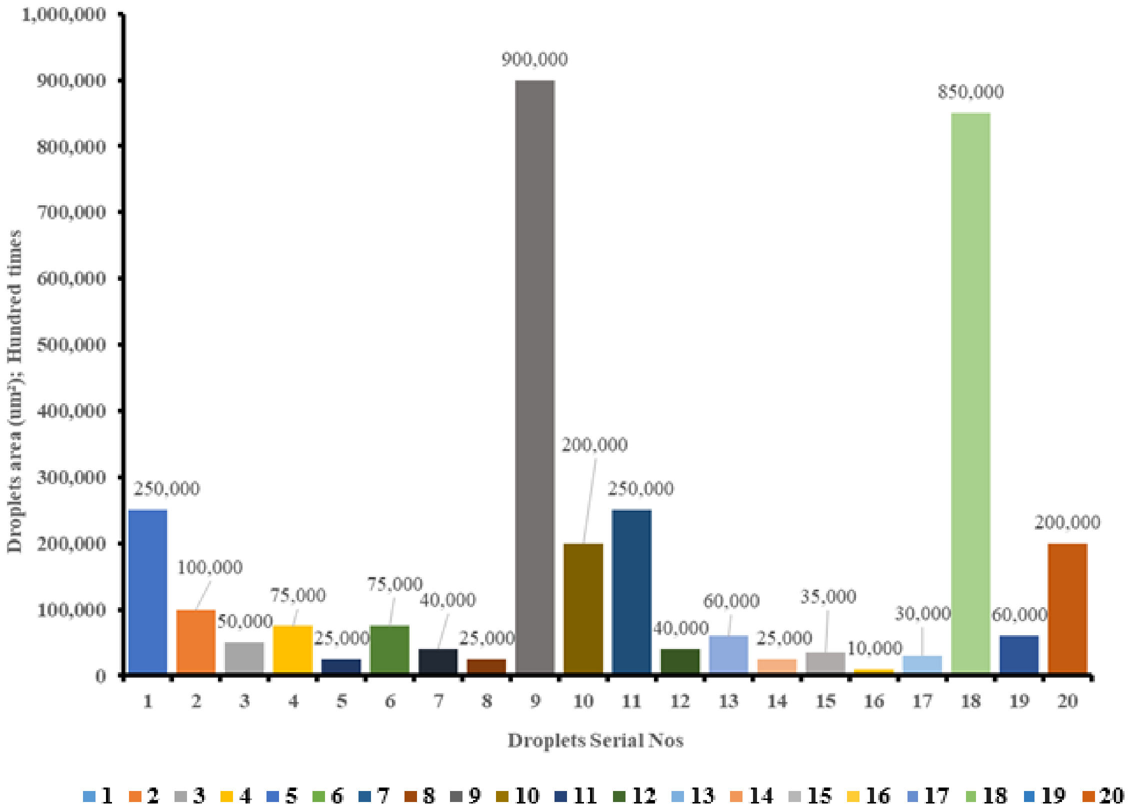
From Table 2, it was depicted that there was a highly significant difference in spray time requirement between the boom sprayer and the other two treatments T_2 and T_3 but it was almost closer between the treatments T_2 and T_3. There was the least significant difference in tiller damage among three treatments T_1, T_2 and T_3. On the other hand, there were highly significant differences in the presence of weed before herbicide spraying (Nos/0.25 Sq.m) among four treatments but the least significant difference was found among all treatments in the presence of weed after herbicide spraying (Nos/0.25 Sq.m). There was a non-significant difference in yield for all the four treatments. Moreover, Vadail, Hesky, Bathua, Mutha,

Bontamak, Foskabegun, Durba, and Shyama weeds were found before spraying the selective herbicide mentioned above but after spraying the weeds were also counted and found there the existence of only a negligence number of Vadail, Hesky, Durba.

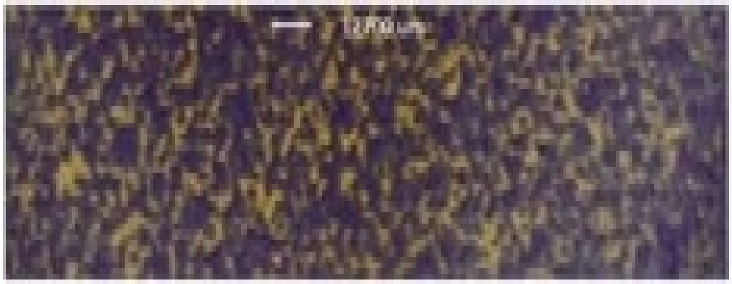
Table 2 Yield and yield contributing characteristics of Barley crops using different types of spraying methods

Treatment	Spray time required/plot (Sec)	Tiller damage (Nos/Plot)	The weed before herbicide spraying (Nos/0.25 Sq.m)	Weed after herbicide spraying (Nos/0.25 Sq.m)	Plant height (cm)	Filled grain/Spike (Nos)	Unfilled grain/Spike (Nos.)	No. of hill/ (0.25 sq.m)	Effective tiller/ (0.25 sq.m)	Panicle or spike/Hill (Nos.)	Yield (t ha^{-1})
Boom Sprayer (T_1)	9.11 b	5.67a	149c	12bc	79.54a	48.37a	4.47 a	42a	73.33a	8 a	2.37a
Electric Knapsack Sprayer (T_2)	51.57a	4.67a	107 d	6 c	74.92a	40.93 a	4.4 a	47.67a	73a	7a	2.23a
Manual Knapsack Sprayer (T_3)	53.77a	4.33a	160b	15 b	77.43 a	45.6 a	4.47 a	39.33a	78.67a	8a	1.97a
Control (T_4)	NA	NA	192 a	152a	80.11 a	43 a	2.4 a	47a	78.33 a	7 a	2.00 a
CV (%)	17.49	31.49	2.08	7.97	7.14	13.83	56.06	22.56	18.26	9.26	17.09
Level of Significance	***	*	***	*	NS	NS	NS	NS	NS	NS	NS

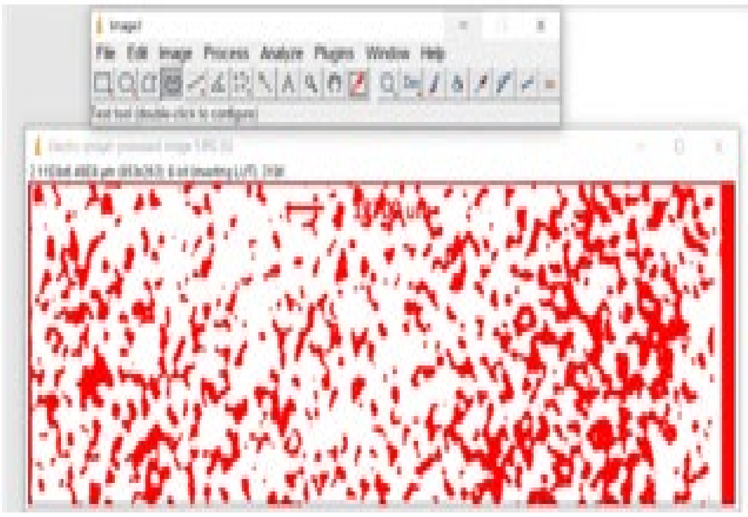
Note: Here, in a column, figures with the same letter or without letters do not differ significantly whereas figures with dissimilar letters differ significantly (as per DMRT). Significant codes: '***' 0.001 '**' 0.01 '*' 0.05



(a) Electric Sprayer droplets distribution pattern

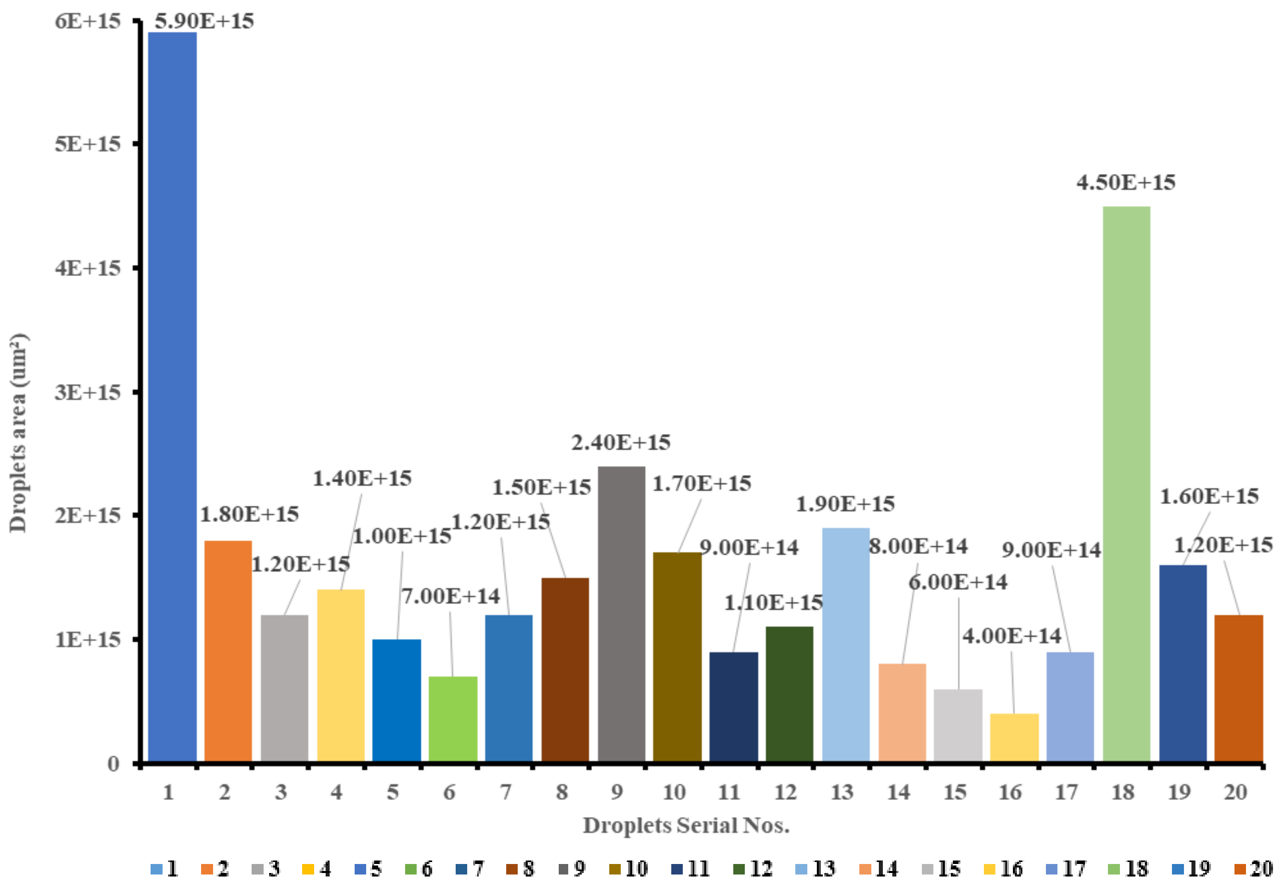


(b) Image in WSP

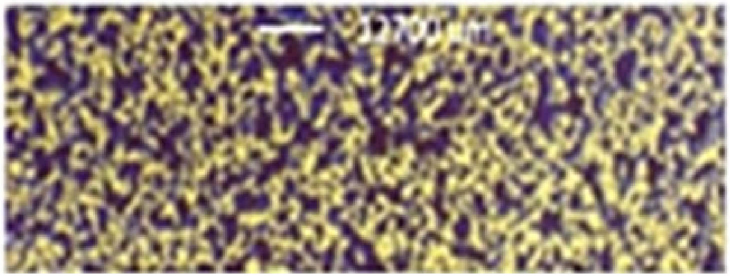


(c) Processed image

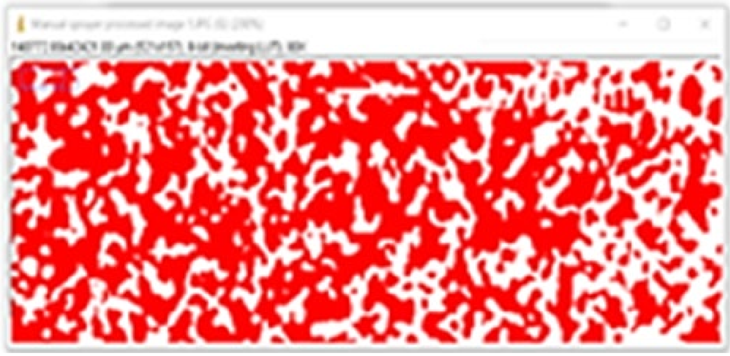
Figure 11 Image based distribution patterns of spray drifts of electric sprayer



(a) Manual knapsack sprayer droplets distribution pattern



(b) Image in WSP



(c) Processed image

Figure 12 Image based distribution patterns of spray drifts of manual knapsack sprayer

4 Conclusion

The petrol engine-operated boom sprayer underwent gradual enhancements from 2020 to 2023, resulting in a robust spray unit. This unit comprises a 100-liter capacity tank made of mild steel (MS) sheet, an engine-operated spray pump, and two booms equipped with a total of six nozzles, along with a mounting frame for adjustable boom height ranging from 500 mm to 900 mm to accommodate various crop heights. The nozzle spacing was standardized at 500 mm within the boom. Following the improvements, the boom sprayer underwent dry run testing at a forward speed of 2.6 km h^{-1}, revealing remarkable performance metrics. Specifically, the sprayer demonstrated an effective coverage width of 2.9 m, theoretical field capacity of 0.8 ha h^{-1}, effective field capacity of 0.7 ha h^{-1}, and an impressive efficiency rating of 93%. These metrics notably surpassed those of manually operated electric rechargeable knapsack and manual knapsack sprayers. Subsequent field evaluations showed no significant difference in yield, yet a highly significant disparity was observed in the time required for spraying operations.

Funding

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Acknowledgements

The authors expressed profound gratitude to Mohammad Habibullah, Manager, stewardship, Syngenta Bangladesh Limited at Syngenta for providing water-sensitive paper for use in image analysis of spray droplet distribution patterns.

References

Ambaliya, P. S., V. K. Tiwari, and M. V. Jalu. 2022. Development and performance evaluation of mini tractor operated sprayer cum weeder. *International Journal of Agricultural Innovation and Research,* 11(1): 39-48.

Agriculture Sector Review (ASR). 2006. *Actionable Policy Brief and Resource Implications.* Dhaka: Ministry of Agriculture, Government of the Republic of Bangladesh.

Bangladesh Bureau of Statistics (BBS). 2017. Statistical Yearbook of Bangladesh. Dhaka, Bangladesh: Ministry of Planning, People's Republic of Bangladesh.

Bangladesh Bureau of Statistics (BBS). 2019. Statistical Yearbook of Bangladesh. Dhaka, Bangladesh: Ministry of Planning, People's Republic of Bangladesh.

Hunt, D. R. 1978. *Farm Power and Machinery Management.* **7th ed.** Ames, Iowa: Iowa State Press.

Issa, W. A., B. Abdulmumuni, R. O., Azeez, I. N. Okpara, J. O. Fanifosi, and O. B. Ologunye. 2020. Design, fabrication, and testing of a movable solar operated sprayer for farming operation. *International Journal of Mechanical Engineering and Technology,* 11(3): 6-14.

Jalu, M. V., R. Yadav, and P. S. Ambaliya. 2023. A comprehensive review of various types of sprayers used in modern agriculture. *The Pharma Innovation,* 12(4), 67-73.

Kakade, R. V., S. M. Lanjewar, S. M. Shreyash, A. U. Kadu, R. R. Dethe, S. R. Lohkare, S. P. S. K. Shukla, and M. S Mohije. 2018. Fabrication of wireless operated solar pesticide sprinkler. *International Journal of Advance Research and Innovative Ideas in Education,* 4(2): 2395-4396.

Kepner, R. A., R. Bainer, and E. L. Barger. 1978. *Principles of Farm Machinery*. **3rd ed.** USA: The AVF Publishing Co., Inc.

Khan, A. S., R. Rafiq, A. Nadeem, and A. Hameed. 1997. Application technology for agrochemicals in Pakistan. In *Proceedings of the International Workshop on Safe and Efficient Application of Agro-chemicals and Bio-products in South and Southeast Asia* 79-101. Bangkok, Thailand, 28-30 May, 1997.

Krishna, M. B., R. Kanwar, I. Yadav, V. and Das. 2017. Solar Pesticide Sprayer. *International Journal of Latest Engineering Research and Applications*, 2(5): 82-89.

Mishra, P. K., M. Kumar, V. K. Shivam, D. K. Singh, R. J. Singh, A. Kumar, and A. Gupta. 2023. Development of battery operated walk behind type sprayer. *The Pharma Innovation,* 12(9): 143-149

Mittal, V. K., B. S. Bhatia, and S. S. Ahuja. 1996. A study of the magnitude, causes and profile of victims of accidents with selected farm machinery in Punjab. Final Report of ICAR Adhoc Research Project, Department of Farm Power and Machinery, Punjab Agricultural University, Ludhiana.

Rabbani, M. A., M. S. Basir, S. M. Rifat, and N. Mona. 2020. Modification of boom for a lever operated knapsack sprayer. *Journal of Science, Technology and Environment Informatics,* 8(02): 595-605.

Tudi, M., H. D. Ruan, L. Wang, J. Lyu, R. Sadler, D. Connell, C. Chu, and D. T. Phung. 2021. Agriculture development, pesticide application and its impact on the environment. *International Journal of Environmental Research and Public Health,* 18(3): 1112.