ISSN 2518–2021 (Print) 2415–4474 (Electronic)

**Fundamental and Applied Agriculture**

Journal home page: https://www.f2ffoundation.org/faa/index.php/home

Vol. 11 (1), pp. 17 – 22: 2026, doi: https://doi.org/10.5455/faa.306106

Agricultural Engineering | ORIGINAL ARTICLE

# Fabrication and Performance Evaluation of a Semi-Automatic Sprayer

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**ARTICLE INFO**

**Article history**
Received: 20 Nov 2025
Accepted: 19 Feb 2026
Published online: 31 Mar 2026

**Keywords**
Application rate, Cost, Field capacity, Field efficiency, Sprayer

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**ABSTRACT**

In the agriculture industry, spraying pesticides is a crucial task for protecting crops from insects and achieving high yields. In Bangladesh, various types of pesticide sprayers are available on the market. However, farmers have mostly been applying pesticides using conventional methods, such as hand-operated and fuel-operated sprayer systems. A worker can typically operate a hand sprayer continuously for only five to six hours, and a fuel-operated sprayer requires fuel, which is expensive, pollutes the environment, and is difficult to find in remote areas. Also, certain pesticides are harmful to human health and can induce lumbar discomfort because of the weight of the equipment, and the farmer who is spraying them is also impacted by them because he comes into close contact with them. Furthermore, manual sprayers have limitations in maintaining the required pressure, leading to ineffective control of pests and loss of pesticides due to dribbling or drift during application. The goal of the study was to design and develop a semi-automatic sprayer to evaluate its technical performance. The proposed machine consists of a frame, PLC, sensor, battery, DC motor, spray tank, and wheel. Every component of the machine was fastened to the frame. The frame was made of a hollow MS bar. The machine's entire fabrication cost was US$ 310. The machine’s application rate was 229 L $ha^{-1}$. The automatic spraying machine's theoretical and effective field capacities were determined to be 0.29 ha $hr^{-1}$ and 0.20 ha $hr^{-1}$, respectively. When the machine was operating at an average speed of 1.51 km $h^{-1}$, its field efficiency was 69%. The machine's yearly cost was US$ 403.63, its capital recovery factor was 0.23, and its capital consumption was US$ 68.2. A significant advancement in agricultural technology, autonomous spraying devices address many of the limitations associated with traditional pest management methods.



## 1. Introduction

Being an agricultural nation, Bangladesh's economy heavily depends on the agricultural sector. Almost half of Bangladesh's workforce works in agriculture, and over 70% of the country's land is used for crop cultivation. The main crops grown include vegetables, fruits, legumes, oil seeds, rice, jute, wheat, and tea (FAO, 2024). Bangladesh's gross domestic product in 2025 was made up of 11 % agricultural, 34.59 % industry, and 51.11 % services sector (Statista, 2025). Bangladesh's population is growing, and modernizing its agricultural sectors is crucial to meeting the country's food needs. The primary causes of decreased crop output include weed, disease, and pest attacks. The most common technique for managing the majority of insects, weeds, and illnesses is chemical management. The chemicals are applied to the crop by dusting, sprinkling, spraying, or using a pump. One of the best and most efficient methods for protecting crops is spraying, which involves administering tiny amounts of spray liquid (Bharatbhai et al., 2017). Spraying pesticides is a crucial task in the agriculture sector to protect crops from insects and achieve high yields, according to research by Charvani et al. (2017). There are many types of pesticide sprayers available. When hand-operated spray systems are employed, efficiency will be low and worker productivity will decline. These problems lead to environmental contamination and ecological imbalance in addition to raising production costs (Bante et al., 2022). Farmers also find manual sprayers to be less ergonomic and outdated, which further complicates their use (Agressianto and Anshory, 2022). A worker cannot use a hand-operated sprayer continuously for more than five to six hours, and a fuel-operated sprayer requires fuel, which is expensive, pollutes the environment, and is difficult to find in remote areas (Islam et al., 2024). These conventional methods are time-consuming and have an impact on people's health. However, the scientific community is concerned about a possible health risk in farming communities because farmers are reluctant to utilize safety precautions. The largest medical university in the nation, BSMMU, voiced alarm over the growing number of cancer patients who have farming ancestry (Hussain, 2013; Talukder et al., 2020). They fear that the farmers' reckless usage of agrochemicals may be the cause of this rebellion. Mechanization of spraying

**Cite This Article**
Milufarzana, Islam M, Banu S, Basak R, Hosen MM, Rahman MM. 2026. Fabrication and Performance Evaluation of a Semi-Automatic Sprayer. *Fundamental and Applied Agriculture*, 11(1): 17–22. https://doi.org/10.5455/faa.306106

equipment ensures that pesticides and fertilizers are applied evenly throughout the farm and lowers waste, preventing losses and waste of input used on the farm (Venkatraman et al., 2018). It will lower production costs. With less input, mechanization increases production, which means that using a semi-automatic sprayer reduces labor, time, and energy while ensuring uniform chemical application. This enhances yield efficiency and crop protection, enabling farmers to produce more with fewer resources. A semi-automatic spray machine can give numerous advantages over the traditional spray machine (Praveen et al., 2024). Chandrashekar et al. (2018) designed and developed a solar-operated push-type sprayer. The actual and theoretical field capacity of push-type solar sprayer were 0.29 ha h-1 and 0.32 ha h-1 for field bean crop with forward speed of 0.53 m s-1, respectively. It was observed that the cost of operation of the solar-operated push-type low clearance sprayer was found to be Rs. 38.5 h-1. Basavaraj et al. (2020) developed and evaluated a solar-operated sprayer. The walking speed of the operator was about 2.5 km h-1, and which corresponds to a theoretical field capacity of about 0.6 ha h-1. The effective field capacity of the sprayer was 0.5 ha h-1, and the field efficiency was 83.33%. The maximum flow rate obtained for four-hole adjustable nozzles with a flow rate of 2.1 l m-1. The application rates for sugarcane and paddy were 195.25 and 154.75 l ha-1, respectively. Banu et al. (2022) designed, developed, and evaluated the performance of a solar-powered sprayer with a water level indicator. The actual and theoretical field capacity of the sprayer were 0.065 ha h-1 and 0.08 ha h-1. The operating cost of the machine was 802 Tk ha-1. Islam et al. (2024) developed a solar-operated pesticide sprayer and reported that the spraying cost of a manually operated sprayer two times of a solar-operated sprayer. Song et al. (2015) reported that a smart spraying system in agriculture is a specialized method designed for precise and cost-effective chemical application while being environmentally friendly. This system comprises a targeted detection system and a spraying mechanism, with the detection system being the core of precise spraying management. The detection system collects information from specific areas, aiding in decision-making for spraying. To minimize the above-stated problem, an attempt was made to develop and performance evaluation of a semi-automatic pesticide spraying machine.

## 2. Materials and Methods

### 2.1. Major components and machine construction

The proposed semi-automatic sprayer consists of a frame, PLC, sensor, battery, DC motor, spray tank, and wheel, as shown in Figure 1 and with dimensions shown in Figure 2. The machine was fabricated in the Agricultural and Industrial Engineering Department laboratory, Hajee Mohammad Danesh Science and Technology University, Dinajpur, Bangladesh from July to September 2024. The frame was made of a rectangular and trapezoidal shape welded together. The frame's lower portion was rectangular, and the upper portion was trapezoidal. The shaft was connected by four wheels to the lower portion of the frame.

A programmable logic controller (PLC) and sensor were attached at the front side of the frame at an angle. The battery, PLC, sensor, and motor were connected by wires. A spray tank and a pump were attached to the inside of the frame. The tank was connected to three adjustable nozzles by a pipe which were attached to the rear side of the frame.

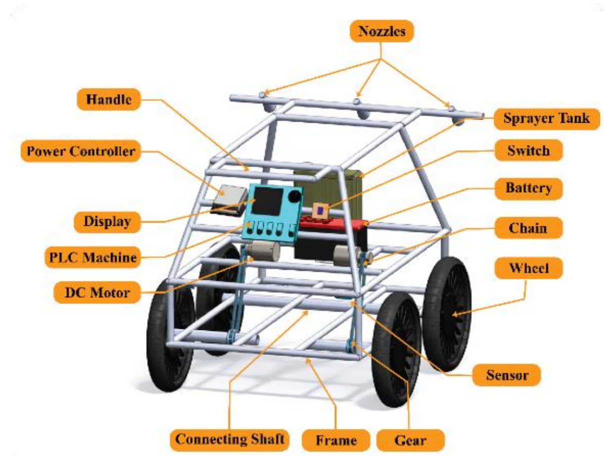


**Figure 1.** Graphical representation of semi-automatic sprayer

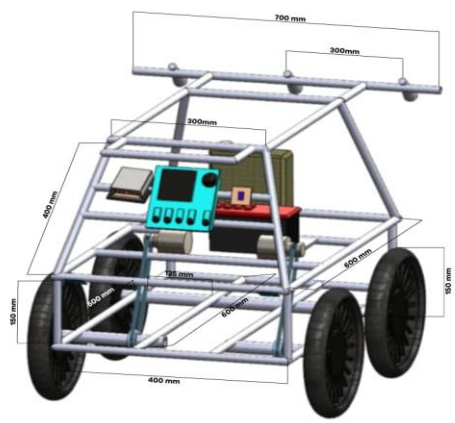


**Figure 2.** Schematic sketching of the machine with dimensions

#### 2.1.1 Frame

The frame was made of a hollow MS bar with an outer diameter of 25.4 mm. Every component of the machine was fastened to the frame. 550 mm shafts supported the entire weight of the frame. To make moving the frame easier, four wheels were mounted on the shafts. For easy movement, two 230 mm iron shafts were made to attach two front wheels with four bearings and one 550 mm shaft was also made to attach the rear wheels with two bearings so that the frame could move easily.

#### 2.1.2 PLC

A Delta DVP-14SS2 PLC (Table 1) was used to make the spray machine automated. The PLC was attached to the front section of the machine with the help of an angle.

#### 2.1.3. Sensor

A photoelectric sensor (NPN NO) (Figure 3) detected the boundary line and passed this message to the PLC. The sensor was connected to the battery and PLC through wires. Table 2 shows the details of the sensor.

**Table 1.** Specifications of PLC

| | |
|---|---|
| Model | Delta DVP14SS2 |
| Operating voltage | 24V |
| Digital Inputs | 8 (expandable) |
| Digital Output | 6 (expandable) |
| Programming language | Ladder logic |

**Figure 3.** Photoelectric Sensor

**Table 2.** Specifications of sensor

| | |
|---|---|
| Operating voltage | DC 6-36V |
| Detection Range | 5-30 cm |
| Response time | 1 ms |
| Working current | 200 mA |

### 2.1.4. Battery and DC (direct current) motor

Table 3 displays the details of the battery and 12V two DC motors attached to the bottom frame to give stability.

**Table 3.** Specifications of battery

| | |
|---|---|
| Model | Tiger 12N9A-BS |
| Weight | 2.77 Kg |
| Output Power | 12V 9 amp |

### 2.1.5. Sprayer tank

The sprayer tank was intended for keeping liquids and spraying the liquid automatically with the help of their inside micro pump and battery. The specifications of the tank are shown in Table 4.

**Table 4.** Specifications of the sprayer tank

| | |
|---|---|
| Dimension | 370 mm × 210 mm × 480 mm |
| Net weight | 2.7 kg |
| Tank capacity | 16 L |
| Working pressure | 0.15-0.40 Mpa |

### 2.1.6. Wheels

The machine's weight was supported by four heavy-duty solid nylon wheels, each measuring 200 mm in diameter, 20 mm in thickness, and 40 mm in width. It ensures smooth movement, consistent spraying, and structural balance.

### 2.1.7. Nozzle and switch

The pipe was receiving liquid from the jar and has three multi-jet plastic nozzles attached to it. One illuminated SPST Rocker Switch (ON/OFF) switch was used to control the whole machine. When the switch is turned on, it connects the PLC (Programmable Logic Controller) and the spray pump to the battery, putting both the spray pump and PLC in the "ON" condition. Once the switch is activated, electric power from the 12V battery flows through the electric wire, supplying DC current to both the spray pump and the PLC. After processing the logic, the PLC sends the required voltage to the motor through the driver, as well as to the sensor mounted on the front side of the machine.

### 2.1.8. Chain and sprocket

To transmit the motor power to the wheel shaft, 2 chains were used. The total number of sprockets used was 4. Two sprockets were attached to the motor shaft and another 2 were attached to the wheel shaft in order to rotate the wheel shaft with the help of a chain.

### 2.2. Working principle of the machine

The component of the machine was selected from previous research work (Islam et al., 2024), and on the basis of need. Two DC motors were connected to the output portion of the PLC through wires. The input portion of the PLC was connected to a photoelectric sensor which passes the instructions through the PLC to the motors that indicate when to stop and start. If the sensor finds any boundary line in the range of 300 mm, it passes the instruction to the PLC to stop the motor and machine stops otherwise, it continues running. The motor then transmits power with the help of the chain and sprocket to the front shaft connected to the wheels. The spraying liquid was drawn from the spray tank by a pump and then sprayed through the adjustable nozzles. A switch was used to control the whole machine and spraying too. The battery was utilized to power the pump. The machine is programmed to run automatically in a straight line, while directional turning is performed manually by the operator. Figure 4 shows the diagram of a working flow chart of the machine.

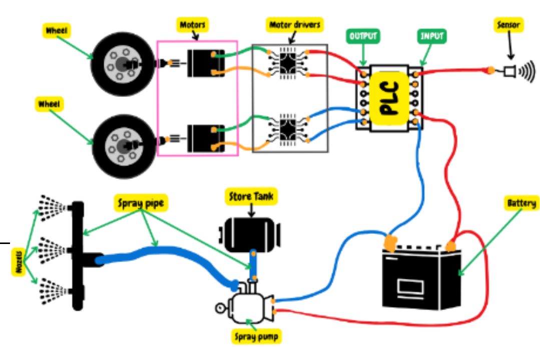


**Figure 4.** Working flow chart of the machine

### 2.3. Experimental site

The experiment of the semi-automatic sprayer was conducted in the experimental field of the agricultural and industrial engineering department, HSTU, Dinajpur, Bangladesh, from 7 to 10 October 2024. The location is 413 km north-west of Dhaka, Bangladesh (25°37′N 88°39′E / 25.617°N 88.650°E). The experimental area was

12750 mm × 6750 mm. For three replications, the test areas were chosen at random from the experimental location.

**Figure 5.** Photographic view of the fabricated machine in operation


**Figure 6 (a-d).** Top, back, front, and side views of the fabricated machine

## 2.4. Performance study of the machine

### 2.4.1. The sprayer's rate of discharge

The following Formula (1) was used to measure the machine's discharge rate (Kepner et al., 1978).

$Dr = V/t$ (1)

Where V is the volume of liquid collected in the cylinder, L; t is the time, min; and Dr is the discharge rate, L $min^{-1}$.

### 2.4.2. Traveling speed

Equation (2) was used to compute the machine's speed (Rabbani et al., 2020).

$S = d/t$ (2)

Where S = Speed, m $s^{-1}$; d = Machine travel distance, m, and t =Time, s.

### 2.4.3. Application rate

Equation (3) was used to compute the application rate of the machine (Chandrashekar and Raghavendra, 2018).

$A = (Q/(S \times W))$ (3)

In this case, A stands for application rate, L $ha^{-1}$; Q for discharge rate, L $min^{-1}$; W for swath width, m; and S for operating speed, m $s^{-1}$.

### 2.4.4. Theoretical field capacity

Equation (4) was utilized to ascertain the sprayer's theoretical field capacity (Kepner et al., 1978).

$TFC = SW/C$ (4)

Where W is the rated width in meters, S is the operating speed in kilometers per hour, C is the constant of 10, and TFC is the theoretical field capacity in ha per hour.

### 2.4.5. Effective field capacity

Equation (5) was utilized to determine the machine's effective field capacity. (Kepner et al., 1978).

$EFC = A/T$ (5)

The formula is as follows: T = total operation time, h; A = area of land covered at the given period, ha; and EFC = effective field capacity, ha $h^{-1}$.

### 2.4.6. Field efficiency

Field efficiency of the automatic sprayer was computed by Equation (6) (Kepner et al., 1978).

$$\text{Field efficiency} = \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}} \times 100 \qquad (6)$$

### 2.4.7. Overlap percentage

Overlap percentage (%) was calculated by the given Equation (7) (Rabbani et al., 2020).

$$\text{Overlap percentage (\%)} = \frac{\text{Dark blue area } (cm^2)}{\text{Total area } (cm^2)} \times 100 \qquad (7)$$

### 2.4.8. Spraying angle measurement

Equation (8) was used to get the spraying angle (θ) (Rabbani et al., 2020).

$\theta = 2 \tan^{-1}((\text{spray width})/(2 \times \text{optimum height}))$. (8)

## 2.5. Cost analysis

A Simple cost analysis of the machine was done. The entirety of the machine's fixed and variable costs is its operating cost. The operation of a semi-automatic sprayer consists of (a) fixed cost-depreciation and interest on investment; (b) variable cost- labour and repair and maintenance cost.

### 2.5.1 Fixed cost (FC)

The depreciation in this study was calculated using the straight-line approach (Barnard and Nix, 1979) using the following Equation (9).

$D = (P-S)/L$ (9)

Where D is the depreciation cost, US$ $yr^{-1}$; P is the machine or implement's purchase price, US$; S is the salvage value, US$; and L is the machine or implement's life (years).

Investment interest was calculated by using Formula (10) (Barnard and Nix, 1979).

$I = ((P+S)/2) \times i$ (10)

Where, i = Interest rate, percentage.

### 2.5.2. Variable costs (VC)

According to Barnard and Nix (1979), the variable cost fluctuates in response to the annual use and changes as the output level changes. However, the cost per hectare remains relatively constant. For every field operation, the machine's variable cost was determined by labor expenditures as well as maintenance and repair expenses. US dollars per hour were used to compute the labor, repair, and maintenance costs.

### 2.5.3. Total operating cost

According to Banu et al. (2022), the machine hour's running cost was calculated using Equation (11).

$TC = FC + VC$ (11)

Where FC stands for fixed cost, US $; VC for variable cost, US $; and TC for operational cost, US $.

### 2.6. Capital Recovery Factor (CRF)

According to Hunt (1977), Equations (12) and (13) were used to determine the capital consumption and capital recovery factors, respectively.

$CC=(P-S)CRF+Si$ (12)

Where, CC = Capital consumption, CRF = Capital Recovery Factor, P = Buying cost of the machine or implement, US $; S = Salvage value, US $; and i = Interest rate, %.

$CRF=(i(1+i)^L)/((1+i)^L-1)$ (13)

Where, i = Interest rate, % and L = Life of the machine or implement, yr.

### 2.7. Annual operating cost

The yearly cost of machine hours was determined using the following Formula (14) (Banu et al., 2022).

$AC = FC + (VC \times T)$ (14)

Where T is the time in hours, AC is the annual cost in US dollars, FC is the fixed cost in US dollars, and VC is the variable cost as well.

## 3. Results and Discussion

### 3.1. Technical performance

Table 5 displays the automatic sprayer's technical specifications. At 1.51 km $h^{-1}$, the sprayer's average flow rate was 1.12 L $min^{-1}$. It was also discovered that the sprayer's swath width was 1.95 m, and its application rate was 229 L $ha^{-1}$. Rakibuzzaman et al. (2023) developed a spraying machine whose flow rate was 1.2 L $min^{-1}$, which is similar to the machine, but the application rate is lower than this sprayer. According to Pachpor et al. (2019) the sprayer's average flow rate was 0.023 L $sec^{-1}$, and the application rate was 112.4 L $ha^{-1,}$ which is lower than this sprayer. In another study by Issa et al. (2020), the sprayer's flow rate was 0.79 L $min^{-1}$, which is lower than this machine. Overlapping loss for the machine was 5.20%, and it seems too high due to the small size of the experimental field. It was discovered that the effective field capacity was 0.20 ha hr-1 and the theoretical field capacity was 0.29 ha $hr^{-1}$. It was determined that the machine's field efficiency was 69% and that the spray angle was 69.52°. Rabbani et al. (2020) found that the effective field capacity of the boom sprayer was 0.145 ha $h^{-1}$, which is lower than that of this sprayer.

**Table 5.** Technical performance of the machine

| Particulars | Observations |
|---|---|
| Forward speed of the sprayer, (km $hr^{-1}$) | 1.51 |
| Rated width, (m) | 1.95 |
| Theoretical field capacity (ha $hr^{-1}$) | 0.29 |
| Effective field capacity (ha $hr^{-1}$) | 0.20 |
| Field efficiency (%) | 69 |
| Application rate (L $ha^{-1}$) | 229 |
| Overlap (%) | 5.20 |
| Spray angle (°) | 69.52 |

### 3.2. Fabrication costs of the machine

Table 6 demonstrates the total manufacturing cost of the machine, and the cost was US $ 310.

**Table 6.** Fabrication costs of the machine

| Material / Instruments name | Cost (US $) |
|---|---|
| MS bar | 13.00 |
| PLC machine | 88.14 |
| Sensor | 8.06 |
| Delta cable | 13.20 |
| Battery | 13.43 |
| Sprayer tank | 15.95 |
| Wheel (4 wheels) | 20.15 |
| DC motor (2 pieces) | 14.27 |
| Charger and charger port | 3.78 |
| Pump | 2.94 |
| Spray nozzle (3 pieces) | 13.91 |
| pipe | 1.68 |
| Chain (2 pieces) | 2.52 |
| Electric wire | 0.84 |
| Bearing (4pieces) | 3.02 |
| Connecting shaft (2 pieces) | 3.36 |
| Sprocket (4 pieces) | 3.36 |
| Nuts and bolts (4 pieces) | 1.68 |
| Gasket tape, hose clip (6 pieces), and alligator clip (2 pieces) | 1.09 |
| Converter (step up and step down) | 1.68 |
| Making charge of frame | 83.94 |
| Total cost | 310.00 |

### 3.3.The machine's cost of operation

Table 7 illustrates the machine's running costs, which came to US $ 2.53 per hectare. When the machine was used for 800 hours a year, its fixed and variable costs were US $ 0.40 $ha^{-1}$ and US $ 2.13 $ha^{-1}$, respectively.

## 4. Conclusion

The semi-automatic spraying machine was fabricated and evaluated. A major development in agricultural technology, the introduction of autonomous spraying devices solves many of the problems with conventional pest management techniques. A PLC-based control system ensures reliable, consistent spraying in harsh field conditions and controls pumps and sensors accurately. Compared to options like Arduino or relay systems, it is more durable, easier to maintain, and more flexible for future upgrades. Based on the findings, the machine's application rate was 229 $Lha^{-1}$. The machine's spray angle and spraying efficiency were found to be 69.52° and 69%, respectively. The machine's running costs came to US$ 2.53 per hectare. Future research can focus on IoT-based monitoring, AI-driven targeted spraying, and variable-rate control using sensors and GPS. Improvements in energy efficiency (e.g., solar power) and integration with autonomous or drone systems can further enhance precision and reduce chemical use.

**Table 7.** Operating costs of semi-automatic spray machine

| Item | | Costs,US$ |
|---|---|---|
| Fixed costs | Purchase price (estimated), US$ | 310 |
| | Salvage value, US$ | 31 |
| | Working life, yr | 7 |
| | Depreciation(US$$yr^{-1}$) | 39.86 |
| | Interest on investment (US$ $yr^{-1}$) | 22.17 |
| Total fixed costs | US$ $yr^{-1}$ | 62.03 |
| | US$ $hr^{-1}$ | 0.08 |
| | US$ $ha^{-1}$ | 0.40 |
| Variable costs | Maintenance (US$ $hr^{-1}$) | 0.007 |
| | Labor (US$ $hr^{-1}$) | 0.42 |
| Total variable costs | US$ $hr^{-1}$ | 0.427 |
| | US$ $ha^{-1}$ | 2.13 |
| Operating costs | US$ $hr^{-1}$ | 0.507 |
| | US$ $ha^{-1}$ | 2.53 |
| Capital recovery factor (CRF) | | 0.23 |
| Capital consumption (US$) | | 68.20 |
| Cost per year (US$) | | 403.63 |

**Funding:** The Institute of Research and Training (IRT) at Hajee Mohammad Danesh Science and Technology University in Dinajpur, Bangladesh, provided funding for this study.

**Author contributions:** Conceptualization, M; methodology, M; software, RB; validation, M, MI, and SB; formal analysis, RB, MMH, MMR; investigation, M, MI, and SB; resources, M; data curation, M, MI, and SB; writing—original draft preparation, RB, MMH, and MMR; writing—review and editing, M, and MI; visualization, M, MI and SB; supervision, M; funding acquisition, M. All authors have read and agreed to the published version of the manuscript.

**Conflict of interest:** The authors declare that there is no conflict of interest regarding the publication of this paper.

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