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Ultrasonic sensor-based automatic control volume sprayer for pesticides and growth regulators application in vineyards

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ABSTRACT

A study was conducted to design a sensor-based control volume sprayer for vineyard cultivation. The study aimed to develop cluster-specific pesticide and growth regulator application systems with improved penetration and minimum off-target losses, thus saving chemicals and overall cost. For the determination of design values of the control volume unit, physical properties (cluster length, width, and level of compactness) of grape clusters from seventeen major genotypes selected from vineyard research farm ICAR-IARI New Delhi were studied. For the design of the grape cluster detection unit, two different types of sensors, i.e., ultrasonic sensor (HC SR-04) and infrared proximity sensor (B0115NCT4U), were evaluated for their ability to detect the target (grape cluster) and the response time. The design of the spraying unit for the control volume sprayer also involved selecting suitable nozzles and operational parameters. The developed sprayer was evaluated for application of plant growth hormone (Gibberellic acid), and the performance was assessed in terms of droplet size, chemical application per cluster, cluster and berry growth characteristics, sprayer application rate, uniformity coefficient, and application time. The data on the physical properties of grape clusters revealed a maximum cluster length and width of 24.00 ± 0.91 cm and 18.80 ± 0.15 cm, respectively. The ultrasonic sensor had a comparatively higher sensing range, beam angle, and lower price than the infrared sensor. The spray uniformity for the hollow cone and flat fan nozzle varied significantly for the operating pressure range of 2–4.5 kg.cm^{-2}. The developed sprayer consisted of a 3D printed control volume unit, ultrasonic sensor, two flat fan nozzles, microcontroller (Atmega 328P), relay switch, voltage converter, spray tank of 16-liter capacity, and 12 VDC battery. In case of developed sensor-based control volume sprayer, 30% and 35.48% saving in chemical use and application time, respectively, were observed compared to the conventional dipping method. The PGR application method has significant interaction with cluster length and berry growth as the main effect; however, failed to show a significant interaction with cluster width. Maximum cluster growth (16.89 ± 1.72 mm) was observed in PGR application with a developed sprayer.

1. Introduction

Horticulture has become a key driver for India's economic development, contributing about 30.4% to the country's agricultural gross domestic product (GDP). India is on a record agricultural produce of 296.65 million tons of food grains in 2019–20. Horticulture production in the same year reached an all-time high of 320.48 million tons [1]. Among horticultural crops, India has the distinction of achieving the highest productivity in grapes in the world, with a productivity of 25.69 t/ha against the world's productivity of 9.32 t/ha. The country is also a major exporter of fresh grapes to the world. The country has exported 246,133.79 MT of Grapes to the world for a worth of 334.79 million USD during the year 2018–19 [2]. However, the export of grapes from India is often limited by the size and quality of grape clusters. Young fruit clusters are highly susceptible to all major diseases, such as black rot, bunch necrosis, Rhizopus rot, and sunburn. To prevent these diseases, a

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Fig. 1. Measurement of length and width of grape *clusters*.

large variety of pesticides, especially fungicides and insecticides, are applied frequently during the cultivation of grapes. Because of the widespread use of pesticides in grape cultivation, toxic pesticide residue has been reported in various environmental matrices [3]**.** The detection of 27 pesticides out of 171 in grape samples was reported by [4], indicating high pesticide persistence in the grapes even after a long post-application period. Apart from the environmental risk, high pesticide residues affect the quality of grapes and their processed products, ultimately reaching the consumer and causing health hazards. Therefore, in order to prevent health risks, it is important to monitor the presence of pesticides and regulate their levels in grapes [5]. Several spraying technologies are available for the application of disease-control chemicals in grapes. Different spraying technologies for pesticide application in grapes are horizontal triplex pump type spray gun, motorized knapsack sprayer; tractor operated air-blast type high volume and low volume mist blower. Michael et al. [6] reported ground losses in spray gun application systems twice as high as motorized knapsack sprayers and four times as high as tractor-driven high-volume sprayers. Major limitation of these spraying methods is the hindrance provided by grape leaves to grape clusters, inhibiting proper spray coverage and off-target losses. Sprayers with target detection systems can reduce chemical consumption in orchards by 30% and decrease drift by 50%. In addition to pesticide application, different plant growth regulators (PGRs) such as gibberellic acid (GA_3) and Forchlorfenuron (CPPU) are used to increase berry size as well as color suppression of grape clusters. The most effective technology for growth regulator application currently in operation is a tractor-operated electrostatic sprayer that has improved deposition efficiency due to its charging nature. The major limitation of electrostatic spraying technologies is the high initial cost challenging the affordability of small and marginal land-holding farmers. Mechanization policies need to be aimed at small and marginal farmers as this form the major proportion and are further to expand with land fragmentation [7,8]. Traditionally, every grape cluster is dipped into growth regulators and taken in a conical pot to cover each cluster. This practice also demands an alternative for the effective application of growth regulators on the grape cluster with improved penetration, thus saving chemicals and overall cost. This study attempted to develop a spraying technology that can cover three-dimensional grape clusters, detect the presence of grape clusters, and apply chemicals in controlled cluster volume.

2. Materials and methods

The design of an ultrasonic sensor-based automatic control volume sprayer involved the study of the physical characteristics of prominent Indian grape cultivars in designing a control volume unit. The laboratory setup was installed for the evaluation of two sensors for automatic spray application and the study of nozzle characteristics. Comparative field evaluation of sensor–based sprayers with conventional spraying methods was performed in three grapevine cultivars plots. The materials used and methods followed to accomplish the objectives of the study were as follows,

2.1. Study of physical properties of grape clusters and berries of selected genotypes

Physical properties of seventeen prominent grape genotypes of India were considered for the study which included six coloreds (*hybrid ER* R_1 P_{19}, *hybrid* ER-R_1P_{16}, *Hybrid ER* R_2P_{36}, *hybrid BA x BS, beauty Seedless, flame seedless*) and eleven white (*Pusa Aditi, PusaTrishar, Hybrid 75–151, Hybrid 16/2A* R_1P_{15}, *Hybrid 16/2A* R_1P_9, *Hybrid 16/2A* R_1P_{13}, *Tas-e-Ganesh, Pusa Seedless*

Pusa Urvashi, Centennial, Perlette) genotypes. The physical properties studied were:

Cluster length and cluster width

The maximum cluster length at the full berry maturation stage was measured as a distance from the peduncle to the anterior tip of the cluster (Fig. 1) The width of each cluster was measured as the distance between two extremes.

2.2. Design of spraying unit of control volume sprayer

The design of the spraying unit for the control volume sprayer involved selecting a suitable nozzle and operational parameters. sprayer nozzles were required to be placed inside the control volume to cover a whole circumferential area of the grape cluster. Since the maximum distance of the nozzle from the target (grape cluster) was to be restricted to half of the control volume diameter, therefore, available standard patternator (IS 8548:1977) was customized to meet the study requirements and evaluate different spray nozzles at a specified distance from the target.

A spray patternator of 60 cm length and 45 cm width was developed. The developed patternator consisted of eighteen V-shaped channels (2.5 cm wide, 1.5 cm deep, and 60 cm long) set at an inclination of 6° with respect to the horizontal plane (IS 8548:1977). For a collection of sprayed water at the downstream side of the patternator, 18 graduated cylindrical tubes of 100 ml capacity ($\phi = 25$ mm) were placed closely, one each at the downside of the V-shaped channel.

An experimental setup consists of a water tank (200 L) and horizontal triplex pump (max. speed:1000 rpm) powered by an AC motor (max. speed: 1440 rpm with a power requirement of 0.75 kW). The required operating pressure was regulated using a pressure regulator (capacity: 10 kg cm^{-2}) and a flow control valve. The excess water was collected back into the tank using a bypass valve (Fig. 2).

Two hydraulic nozzles (Flat fan [model: XR11002] and hollow cone [model: TXR80015VK], TeeJet Technologies, Wheaton, IL, USA) were evaluated for spray performance at three heights (2.5 cm, 5 cm, 7.5 cm) and five operating pressures (2.5, 3, 3.5, 4, 4.5 kg cm^{-2}). The selected dependent parameters for the study were spray width, discharge rate, spray cone angle, and coefficient of uniformity (CU). The selection of nozzle distance from the target was based on the radius of the control volume and the optimum possible distance of nozzles from a central point of the control volume unit. The pressure range was selected based on the recommended spray pressure (1 to 5 kg cm^{-2}) for pesticide application [9–12].

2.3. Laboratory measurement of spray characteristics

The spray characteristics were measured following guidelines mentioned in Indian Standard IS 8548–1977 [13].

Discharge rate: The spray discharge rate (L min^{-1}) of selected nozzles was obtained at a predetermined level of variables by measuring the total volume collected in graduated cylindrical tubes placed at the downstream side of the customized patternator in a time interval of one minute.

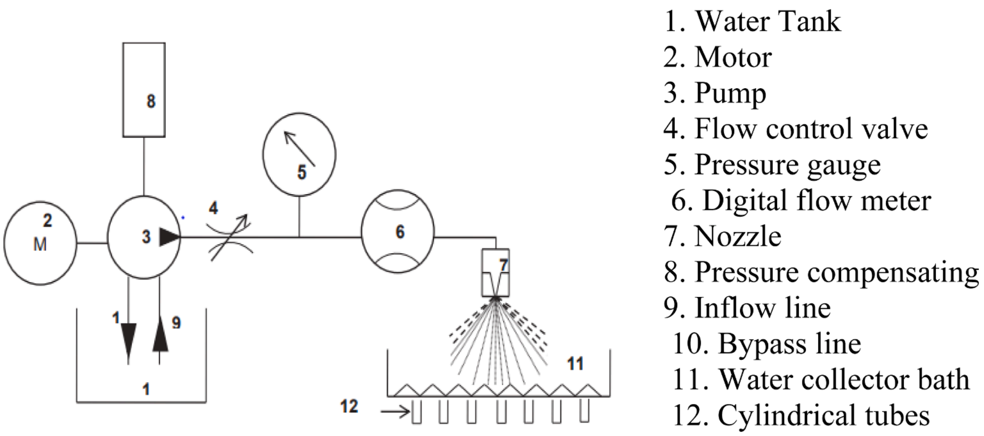


Fig. 2. Flow diagram of experimental set-up for the study of nozzle characteristics.

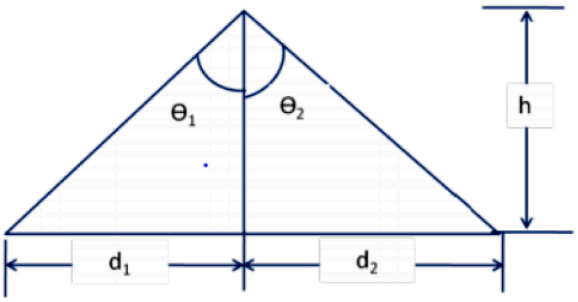


Fig. 3. Spray width and spray cone angle measurement.

Spray width: Total spray width is the sum of the width covered by liquid spray towards either side from the center of a nozzle (13).

$$\text{Spray width (cm)} = d_1 + d_2 \tag{1}$$

Cone angle of the spray: The cone angle of spray (spray angle) for selected nozzles was measured at five operating pressures and selected spray distances by calculating the spray width and height of the nozzle (Fig. 3) from the surface of the patternator using the following equation (Eq. (2)),

$$\text{Cone angle of spray} = \tan^{-1}\frac{d1}{h} + \tan^{-1}\frac{d2}{h} \tag{2}$$

Where, d_1=Length of coverage at left side from a nozzle, mm d_2=Length of coverage at the right side from a nozzle, mm

h = Height of nozzle (2.5 cm, 5 cm, and 7.5 cm)

The spray angle was calculated by adding Θ_1 and Θ_2

Spray uniformity: The uniformity of collected spray liquid on the spray patternator was determined by calculating a coefficient of variation (Eq. (3)).

Coefficient of uniformity = 100 – coefficient of variation

$$\text{coefficient of variation} = \frac{\sigma}{\mu} \tag{3}$$

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{i=n}(x_i - \mu)^2} \tag{4}$$

Where,

σ = standard deviation

μ = meansprayvolume

N= no. of cylinders under consideration x_i = spray volume collected in an individual cylinder

2.4. *Design of sensor-based grape cluster detection system*

The main purpose of developing such a system was to have automatic

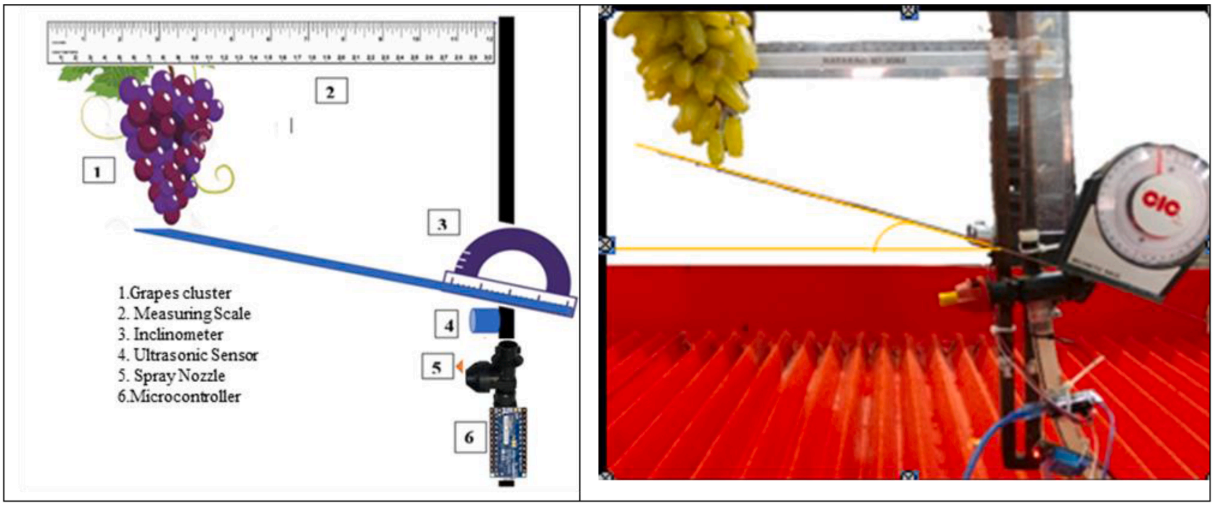


Fig. 4. Experimental setup for evaluation of selected sensors.

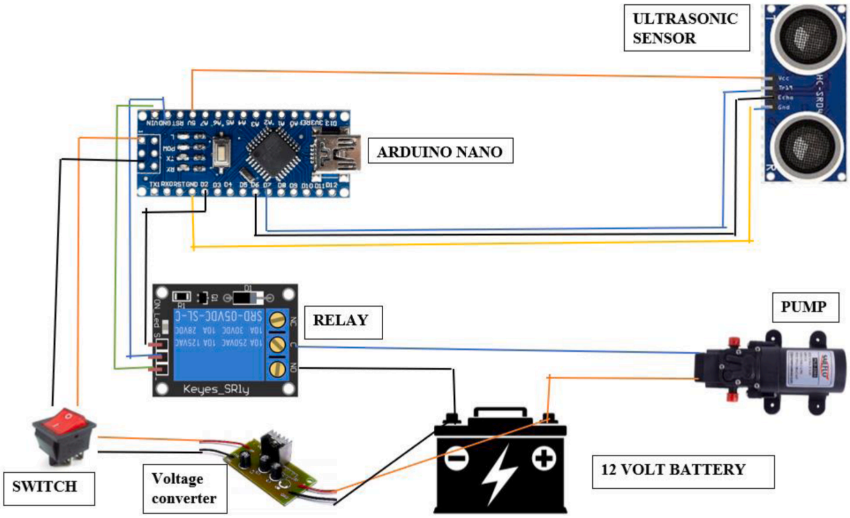


Fig. 5. Circuit diagram for grape cluster detection system and voltage converter.

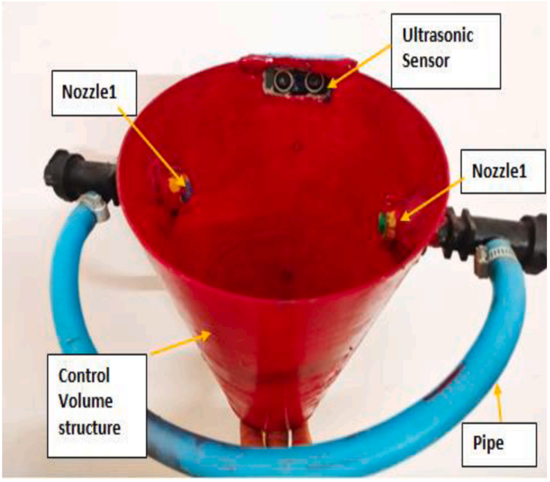
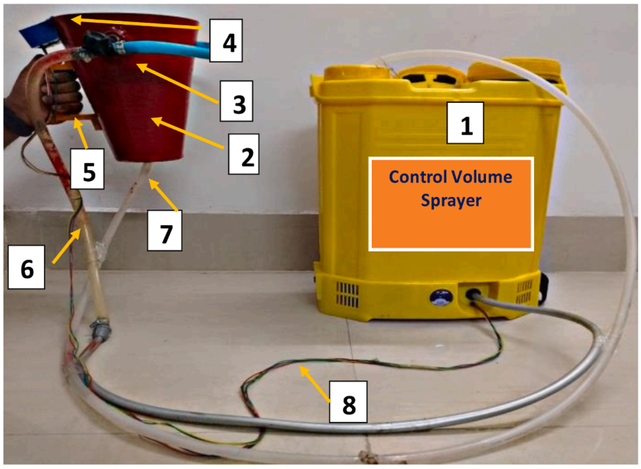


Fig. 6. 3D printed control volume unit.

Table 1
Specification of developed control volume sprayer for grape cluster.

Sr. No	Items	Values
(1)	Dimensions of the tank (L X B X H) mm	1 × 220 × 400
(2)	Tank capacity (Litres)	16
(3)	Material of tank	Plastic
(4)	Pump	
	i Type	Diaphragm type
	ii Flow rate (liter per minute)	3.6
(5)	Dimensions of control volume unit (mm)	
	1) Maximum diameter	200
	2) Minimum diameter	100
	3) Height	250
(6)	Material of control volume structure	Polylactic acid (PLA)
(7)	Overall weight of the prototype	6.5 kg
(8)	Nozzle's type	Flat fan
(9)	Number of nozzles	2
(10)	Type of Sensor	Ultrasonic sensor
(11)	Delivery and return of hoses.	
	1) Diameter (mm)	10
	2) Length (mm)	2000



1. Battery Operated Knapsack sprayer
2. Control Volume Structure
3. Nozzle Assembly
4. Ultrasonic sensor with shield
5. Handle
6. Discharge pipe
7. Liquid Return Pipe
8. Electrical connections for sensor

Fig. 7. Developed sensor-based sprayer along with the control volume structure.

ON and OFF spray nozzles based on the presence and absence of grape clusters detected by the grape cluster detection system. Two distance measuring sensors (ultrasonic sensor (HC SR-04) and infrared proximity sensor (B0115NCT4U)) were evaluated for their grape cluster detection performance using a customized experimental set-up.

A customized experimental setup was developed with a special arrangement for the hanging of grape clusters and provision to facilitate vertical movement (Fig. 4). The experimental setup was fitted with an inclinometer at the pivot point to measure the angle between the sensor beam and the grape cluster. Sensor along with the required component such as a microcontroller (Arduino-nano, Atmega328P), relay module (5 W, Single Channel Relay Module, ERH, India), 12 V diaphragm water pump (maximum flowrate: 5.5 L min^{-1}, RELAXINDIA marketing PVT. LTD., India), battery (12 V, 8 Ampere hours[AH]) and nozzles was installed in a way to have spray nozzle operation triggered through grape cluster detection by the sensor (Fig. 5). Algorithms to operate the experimental setup for two types of sensors were developed and uploaded in Arduino-nano microcontroller through Arduino IDE software (Version 1.8.15, Arduino Software, Ivrea, Italy).

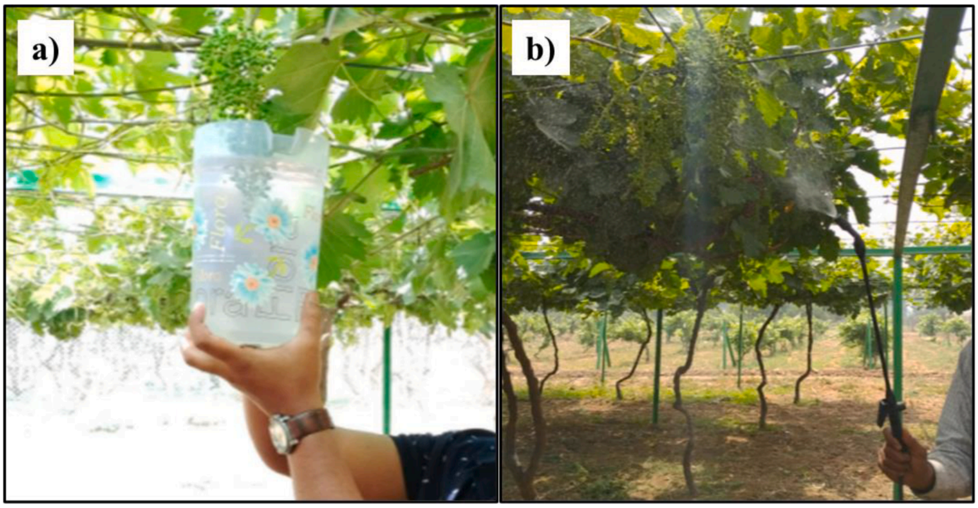


Fig. 8. Conventional PGR application methods, a) Hand dipping b) Manual compressed air sprayer.

Table 2
Variations in cluster width (cm) of selected grapevine cultivars.

Colored (a) Genotype	Mean±SE	White (b) Genotype	Mean±SE
Hybrid ER $^{R}1\ ^{P}19$	9.75 ±0.47^{efghij}	Pusa Aditi	18.80±0.15^{a}
Hybrid ER-R1P16	11.75 ±1.03^{cdef}	PusaTrishar	13.75±1.03^{bc}
Hybrid ER R2P36	10.75 ±1.31^{defgh}	*Hybrid 75–151*	6.50 ±0.64^{mnopq}
Hybrid BA x BS	8.95 ±0.68^{ghijklm}	*Hybrid 16/2A $^{R}1^{P}15$*	8.00 ±1.08^{jklmnop}
Beauty Seedless	11.00 ±1.08^{defg}	*Hybrid 16/2A R1P9*	11.38±1.28^{defg}
Flame Seedless	10.75 ±1.37^{defgh}	*Hybrid 16/2A R1P13*	10.75 ±1.37^{defgh}
		Tas-e-Ganesh	10.75 ±0.47^{defgh}
		Pusa Seedless	10.50 ±0.64^{efghi}
		Pusa Urvashi	11.00±0.40^{cdef}
		Centennial	7.25 ±0.75^{klmnop}
		Perlette	10.65 ±1.29^{defgh}
Group means of a, b LSD ($p \leq 0.05$)	10.49 10.67 1.42	–	10.85

The values show the mean ±standard error of three replicates. When using Tukey's LSD test, means with the same superscript inside a column are not statistically different at the 5% significance level. Different letters in the same column show statistically distinct findings (p 0.05).

Table 3
ANOVA for dependent variable spray uniformity.

Source	DF	Mean Square	F Value	Pr > F
Replication	2	18.56	2.58	0.0842
H	2	25.01	3.48	0.0374
N	1	1127.56	156.88	<0.0001
$H \times N$	2	5.86	0.82	0.4476
P	4	88.26	12.28	<0.0001
$H \times P$	8	194.72	27.09	<0.0001
$N \times P$	4	194.12	27.01	<0.0001
$H \times N \times P$	8	305.79	42.55	<0.0001

(H = Nozzle height, N= Nozzle type, P= Operating pressure).

Table 4
Performance of developed control volume sprayer in comparison to dipping and manual sprayer.

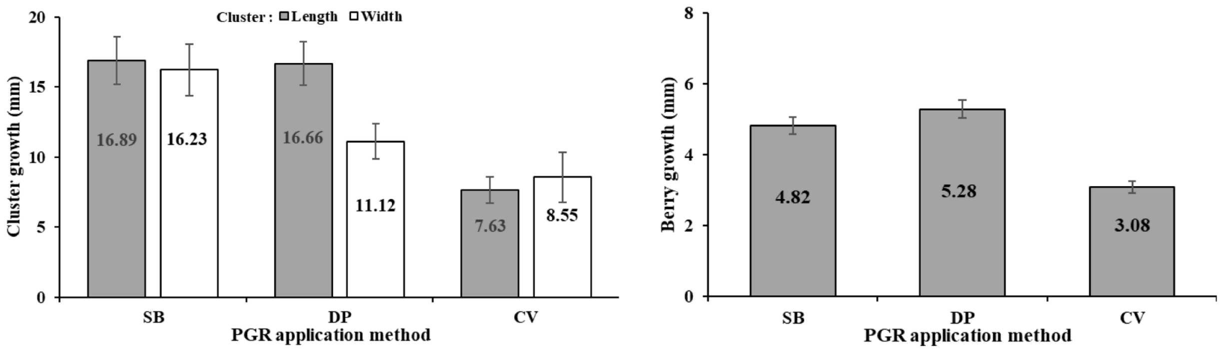
Parameters	Dipping Method	Control-volume sprayer	Manual Sprayer
Working capacity (clusters/h)	500	818	930
Chemical application/ vine	3.6 liter	2.52 liter	2.0 liter
Droplet size (VMD, µm)	—	168	355
NMD, µm	—	70.5	103.6
Deposition (ng cm^{-2})	—	829	95
% Coverage	NA	15.56	5.75

Table 5
Analysis of variance of PGR application methods on cluster growth.

	DF	Mean Length	Mean Width	F value Length	F value Width	Pr (>F) Length	Pr (>F) Width
Treatment	2	4.42	1.34	4.84	1.39	9.84×10^{-3}	0.25
Variety	2	0.36	0.63	0.39	0.65	0.68	0.52
Vine	1	0.27	3.48	0.30	3.60	0.59	0.06
Treatment: Variety	4	1.65	1.01	1.81	1.04	0.13	0.39
Treatment: Vine	2	0.04	0.09	0.04	0.10	0.96	0.91
Variety: Vine	2	0.60	0.13	0.65	0.14	0.52	0.87
Treatment: Variety: vine	4	0.53	0.67	0.58	0.69	0.68	0.60
Residuals	99	0.91	0.97				

Table 6
Analysis of variance of PGR application methods on berry growth.

	DF	Mean	F value	Pr (>F)
Treatment	2	0.45	9.05	2.45×10^{-4}
Variety	2	0.10	2.05	0.13
vine	1	0.00	1×10^{-3}	0.98
Treatment: Variety	4	0.08	1.66	0.17
Treatment: Vine	2	0.06	1.19	0.31
Variety: Vine	2	0.04	0.73	0.49
Treatment: Variety: Vine	4	0.06	1.20	0.32
Residuals	99	0.05		



(a)

(b)

Fig. 9. Effect of PGR application methods on (a) cluster growth (mm) and (b) berry growth (mm).

The performance of selected sensors was evaluated in terms of the ability to detect the target (grape cluster) at three distances (10 cm, 15 cm, and 20 cm) of a sensor from the target and for different angular positions (15° to 60°).

2.5. Control volume sprayer for grape clusters

Based on a study of the physical properties of grape clusters, the control volume structure for grape cluster spraying was designed with an overall length of 25 cm and width of 20 cm to accommodate the clusters of major grape varieties. The control volume unit was designed on computer-aided design software Creo-parametric (version 7.0, Parametric Technology Corporation, MA, USA). Provision was made in the design to fit different components into the structure, i.e., two nozzles on the top inner side opposite to each other, an ultrasonic sensor on the inner side of the upper end, and a return pipe at the bottom of the control volume.

The control volume unit was fabricated using a 3D printing system with Polylactic acid (PLA) as a printing material (Fig. 6). Laboratory testing of nozzles revealed that the flat fan nozzle was better regarding spray width, spray cone angle, and uniformity coefficient in the operating pressure range of 2.5 to 4.5 kg.cm^{-2}. Therefore, a flat fan nozzle was selected for the development of the spraying unit. Due to comparatively greater beam angle, higher sensing range, and low cost, ultrasonic sensing was selected for the design of the grape cluster detection system. The other functional components of the control volume sprayer were the spray tank (16 L), pumping unit, power pack, and delivery hoses. The power pack included a battery (12 V, 8 AH capacity), Table 1. To operate the microcontroller unit, a 12 V DC supply from the battery was converted into 5 V with the help of a voltage converter ic (LM7805). As the grape cluster enters the control volume structure, the ultrasonic sensor fitted on the structure detects the presence of the cluster at the entry-level. The sensor sends a signal to the microcontroller, which operates the relay switch. The relay switch actuates the pump. Once the pump of a sprayer turns ON, liquid from the tank gets delivered to the nozzles fitted inside the control volume structure, and thus, the spraying of the grape cluster starts. The spraying continues till the cluster remains within the control volume unit. As soon as the grape cluster's end portion (tip) comes out of the control volume unit, the whole system stops, and any chemical falling back within the control volume unit is recovered in the tank through a return hose. A battery-operated mechanical knapsack sprayer (model no: SG-055, 16 L, Super Green Ltd., India) was adopted for retrofitting the developed cluster sensing and spraying unit (Fig. 7).

2.6. Field performance evaluation of developed sprayer

The developed sensor-based control volume sprayer for grapes clusters was evaluated for its spray performance and plant growth regulator (PGR) application efficacy in Vineyard Research Farm of Indian Agricultural Research Institute, New Delhi (28°38′22.1″N 77°09′38.2″ E) during 2020–2021. The spray performance was evaluated regarding spray coverage, chemical application per cluster, and sprayer application time. Three different plots of vineyards consisting of three different varieties (*Pusa Swarnika, Pusa Trishar, and Flame seedless*), respectively representing compact, semi-compact, and loose clusters, were selected for PGR application efficacy. Three treatment methods (developed sensor-based sprayer (SB), conventional hand dipping (DP), and manual compressed air sprayer (Model no: B0BKTCQG5H,5 L, compressed air sprayer, Saiagro Ltd., India) were used for plant growth hormone (*Gibberellic acid (GA_3)*) at an application rate of 40 ppm, and its effect on cluster and berry growth (mm) was evaluated (Fig. 8).

Water-sensitive papers (WSPs, Size: 76 mm × 52 mm, TeeJet technologies, Illinois, USA) were used for spray coverage assessment [14–16]. WSPs were placed on the randomly selected three clusters per vine (three vines per treatment). A total of 54 WSPs (2 treatments × 3 vines per treatment × 3 clusters per vine × 3 replications) were sprayed with tap water to measure the spray coverage of the developed sprayer and conventional manual sprayer. The dipping method did not assess spray coverage because it involves direct chemical application without atomization. The working capacity for each treatment method was calculated based on the number of clusters sprayed per hour. Chemical application per vine was calculated based on the difference in the chemical level in the tank before and after applying water to every cluster of 9 vines (3 vines per treatment).

Cluster size (length and width) and berry diameter were measured using a measuring scale (range:300 mm) and vernier caliper (model no: Digical159, Measurement Range: 0 – 150 mm; Resolution: 0.01 mm; Accuracy: $\hat{A}$±0.05 mm, Zhart ltd., India) before and 20 days after GA_3 application [23], respectively. A total of 135 clusters (3 (treatments) × 3 plots (varieties) × 3 (vines) × 5 (replicates)) were assessed for cluster and berry growth. The average berry diameter was calculated by randomly measuring the diameters of 10 berries per cluster.

2.6.1. Data analysis

The physical properties of grape clusters of selected grapevines were analyzed using Tukey's LSD test. Analysis of variance (ANOVA) was performed for nozzle spray characteristics optimization, and results were interpreted at a 5% significance level. WSPs were collected on labeled paper sheets after 15 min of spray trials. Collected WSPs were digitized using a scanner (HP Officejet Pro 9015e, Hewlett-Packard Company, USA). Digitized WSPs were analyzed using DepositScan (USDA-ARS, USA) to obtain percent spray coverage, deposition (ng cm^{-2}), volume mean diameter (VMD), and number mean diameter (NMD). To determine the efficacy of the PGR application method on cluster and berry growth, statistical ANOVA was performed at $\alpha = 0.05$. The cluster and berry growth datasets were normalized using cube-root transformation. All the statistical analysis was performed in RStudio programming software (version: 2022.12.0 + 353, public-benefit corporation, USA).

3. Results and discussion

The developed prototype consisted of different functional components, i.e., sensor-based cluster detection system, control volume unit appropriate to the size of grape clusters, spraying unit, power unit, chemical storage tank, and delivery system. A sensor-based control volume sprayer was developed through various laboratory and field experiments. The major results obtained from those experiments are presented as follows.

3.1. Variations in physical characteristics of major Indian grape genotypes

All the selected genotypes' mean cluster lengths ranged from 14– 24 cm. The cluster length was 14– 19 cm in colored genotypes, whereas cluster length ranged from 13.5 cm to 24 cm in the case of white genotypes. The minimum cluster length of 13.5 cm was observed for *hybrid 16/2A* $R_1P_{13,}$ while the maximum cluster length of 24 cm was observed for *hybrid 16/2A* $R_1P_{9.}$

Similarly, the cluster width of selected genotypes ranged from 8.95–11.75 cm and 6.50 18.80 cm for colored and white genotypes, respectively. The maximum cluster width of 18.80 cm was observed in *Pusa Aditi,* whereas the minimum cluster width of 6.5 cm was observed in *hybrid 75–151*. The data on the physical properties of grape clusters revealed a maximum cluster length of 24.00 ± 0.91 cm and maximum cluster width of 18.80 ± 0.15 cm (Table 2). This agrees with the findings of a study on the variability of cluster and berry characteristics of different genotypes under the subtropical grape growing condition in India [17].

Hence, the optimum length and width were respectively taken as 25 cm and 20 cm for the design of the control volume unit of the sensor-based grape cluster sprayer.

3.2. Comparative performance of the ultrasonic sensor and infrared sensor in grape cluster detection

The ultrasonic and infrared sensors were evaluated for their performance to develop a sensor-based grape cluster detection system. The maximum beam angle of the ultrasonic sensor was 30° with a maximum sensing range of 100 cm. For angles greater than 30°, cluster presence was not detected. In comparison, the performance of the infrared proximity sensor revealed the maximum sensing angle and sensing range as 20° and 15 cm, respectively. The ultrasonic sensor had a larger sensing range and sensing beam angle than the Infrared sensor [18]. The infrared proximity sensor's performance was affected by the presence of sunlight compared to the ultrasonic sensor. Based on greater beam angle, higher sensing range, and comparatively lesser cost, an ultrasonic sensor was selected to develop a grape cluster detection system.

3.3. Performance of selected nozzles at varying pressures and operational heights

The study of spray parameters of selected flat fan and hollow cone nozzles revealed that the discharge rate at a selected range of operating pressure in the case of the flat fan nozzle was higher than in the hollow cone nozzle. The discharge rate of the flat fan nozzle was found in the range of 1.10–1.47 L min^{-1}, whereas the discharge rate of the hollow cone nozzle ranged from 0.758 L min^{-1} to 1.02 L min^{-1}. An increase in the nozzle discharge with the increase in pressure was observed in both nozzles; however, nozzle discharge remained unaffected by the change in nozzle height. The maximum value of spray width in a flat fan nozzle was 22.5 cm, whereas the maximum spray width in a hollow cone nozzle was only 17.5 cm. It was observed that spray width increased with increased operating pressure and nozzle height. Kumar et al. [19] reported a substantial change in mean discharge and spray width for varied nozzle heights and operating pressures for the selected hydraulic nozzles. The spray cone angle of the flat fan nozzle was 135° at an operating pressure of 3.5 kg cm^{-2}. Bijarniya et al. [20] revealed that the spray angle increased as the pressure increased for all types of selected nozzles. Due to the fine atomization of spray droplets, the spray angle for a flat fan nozzle was maximum for a given pressure.

Based on the spray uniformity ANOVA (Table 3), it can be observed that spray uniformity varied significantly for nozzle type and operating pressure. The maximum value of spray uniformity obtained with the flat fan nozzle was 83.72%. However, the maximum value of spray uniformity in the hollow cone nozzle was 73.90%.

The laboratory evaluation of selected nozzles showed that a flat fan nozzle has more discharge rate, spray width, and spray uniformity than a hollow cone nozzle. Hence, a flat fan nozzle was more suitable to be used in the design of the spraying unit of the sensor-based control volume sprayer. Based on the spray angle of the flat fan nozzle, it can infer that at least two such nozzles were required for complete coverage of the grape cluster transversely during spraying. Hence, in the design of the spraying unit of the control volume sprayer, two flat fan nozzles were placed diagonally opposite each other inside the control volume unit.

3.4. Performance of sensor-based control volume sprayer

The application time with the hand dipping method (DP)[Grower control-1] was higher compared to the spraying with a sensor-based sprayer(SB) and a conventional manual compressed air sprayer (CS) [G*rower control*-2]. Dipping required more operational time due to the complete manual mode of chemical application and the tedious activities involved in dipping, such as holding a conical pot for a longer duration and the requirement of frequent refilling (Fig. 5a). The chemical requirement was less with SB than the DP due to the spray atomization and liquid return mechanism involved in the control volume sprayer. Field evaluation data shows that SB can save up to 30% of chemicals and 35.48% time of application compared to DP. The major limitation of using CS was that the off-target losses were higher than SB due to more canopy hindrance and higher drift. Droplet size analysis has shown that VMD and NMD were lower due to higher atomization in the case of SB. Small droplet sizes and the site-specific nature of application resulted in significantly higher droplet deposition on the grape cluster in SB (829 ng cm^{-2}) compared to CS (95 ng cm^{-2}) (Table 4).

3.5. Effect of the PGR application method on the grape cluster and berry growth

The ANOVA showed a significant difference in the cluster length ($F_{2,99} = 4.84$, $p = 9.84 \times 10^{-3}$). However, it failed to show significant differences in cluster width ($F_{2,99} = 1.39$, $p = 0.25$) with the application method as a main effect (Table 5). Change in cluster length (Mean ± Std. Error) observed in PGR application methods, sensor-based (SB) sprayer, hand dipping (DP), and conventional manual sprayer (CS) were 16.89 ± 1.72, 16.66 ± 1.55, and 7.63 ± 0.94 mm respectively. Maximum growth in cluster width was observed in SB (16.23 ± 1.84 mm), followed by DP (11.12 ± 1.28 mm) and CS (8.55 ± 1.77 mm), respectively. Cluster growth was comparable in SB and DP methods, and the least growth was observed in the CS method. It may be because of higher atomization and more spray deposition on clusters under control volume conditions. As the droplet size plays a vital role in spray deposition [21,22], due to smaller droplet size in the control volume sprayer, more spray deposition and spray coverage were obtained.

ANOVA based on cube root transformed berry growth data shows significant interaction in berry growth and PGR application method as the main effect ($F_{2,99} = 9.05$, $p = 2.45 \times 10^{-4}$) (Table 6). Maximum growth in berry diameter was observed in DP (5.28 ± 0.25), followed by SB (4.82 ± 0.25) and CS (3.08 ± 0.17), respectively. The effect of PGR application methods measured in terms of berry growth after 14 days of treatment reveals that berry growth (mm) was comparable in SB and DP methods [23]. However, berry growth was significantly less in CS, possibly due to its higher off-target losses and less spray coverage (5.75%) than SB. Abu-Zahra [24] evaluated the effect of plant growth regulator application methods (DP, SB, and CS) on the growth characteristics of grapes cluster and reported similar research finding that grapes cluster and berry growth characteristics varied significantly with different growth regulator application methods. No significant difference in the cluster (Length: $F_{2,99} = 0.39$, $p = 0.68$; Width: $F_{2,99} = 0.65$, $p = 0.52$) and berry growth ($F_{2,99} = 2.05$, $p = 0.13$) was observed with grapevine variety as the main effect (Fig. 9).

4. Conclusions

Ultrasonic sensors can suitably be used in the design of sensor-based sprayers due to their higher beam angle, sensing range, and better response time than Infrared sensors. The flat fan nozzle was best suited for control volume spray due to adequate spray angle (135°), spray width (22.5 cm), and spray uniformity (83.72%) at selected target spray distance and operating pressure. The chemical application method significantly affects grapes' cluster and berry growth characteristics. With a developed sensor-based control volume sprayer, 30% saving in chemical use and 35.48% saving in operational time could be attained compared to the conventional dipping method.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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References

[1] S. Choudhary, Economic dualism subverting rural reforms: drawing parallels from mgnrega and farm bills, 2020, Pragati J. Indian Econ. 8 (1) (2021) 60–76.
[2] R. Jayasankar, V. Sneha, T. Balakrishnan, Factors influencing the grape growers with their apotion level of cultivation practices in Tamil Nadu, Pramana Res. J. 9 (2) (2019) 579–586. VolumeIssue.
[3] U.S. Pujeri, A.S. Pujar, S.C. Hiremath, M.S. Yadawe, Status of pesticide residue in grapes of Bijapur, Recent Res. Sci. Technol. 2 (2) (2010) 100–102.
[4] M.K. Raikwar, V. Bhardvaj, U. Sawant, V. Vora, Study of contamination level of pesticide residues in grapes (Vitis vinifera) in Maharashtra, Green Pages (2011) 108–117.
[5] S. Grimalt, P. Dehouck, Review of analytical methods for the determination of pesticide residues in grapes, J. Chromatogr. A 1433 (2016) 1–23.
[6] C. Michael, E. Gil, M. Gallart, M.C. &Stavrinides, Influence of spray technology and application rate on leaf deposit and ground losses in mountain viticulture, Agriculture 10 (12) (2020) 615.
[7] R.A. Parray, M. Indra, K. Adarsh, T.K. Khura, S.D. Lande, Pilot study of farm v power-machinery status and custom-hiring opportunities in rice (Oryza sativa)-wheat (Triticum aestivum) cropping system, Indian J. Agric. Sci. 86 (2) (2016) 167–172.
[8] R.A. Parray, T.K. Khura, S.D. Lande, Factors affecting agricultural mechanization acase study from Aligarh Division of Uttar Pradesh, Agric. Eng. Today 43 (4) (2019) 1–5.
[9] Indian Standard Institution, Indian Standard Test Code for Power Operated Hydraulic Sprayer, IS: 8548–1977, Indian Standard Institution, 1978.
[10] S. Sukumaran, G.S. Manes, S.K. Singh, A. Singh, A. Dixit, Effect of spraying pressure and usage on discharge rate and wear of hollow cone nozzle having different nozzle tip material, J. Agric. Eng. 50 (1) (2013) 1–8.
[11] Matthews G.A. 1992. *Pesticide Application Methods*. Harlow, UK: Longmans. 405 pp. 2nd ed.
[12] Nozzle-Selection and Sizing, University of Nebraska Lincoln Extension, Institute of Agricultural and Natural Resources, 2011 publication EC141, https://extensionpublications.unl.edu/assets/pdf/ec141.pdf. accessed: July 2019.
[13] D. Padhee, S. Verma, S.S. Rajwade, H. Ekka, S.K. Chandniha, S.K. Tiwari, Evaluating the effect of nozzle type, nozzle height and operating pressure on spraying performance using a horizontal spray patternator, J. Pharmacogn. Phytochem. 8 (4) (2019) 2137–2141.
[14] L.R. Khot, R. Ehsani, G. Albrigo, P.A. Larbi, A. Landers, J. Campoy, C. Wellington, Air-assisted sprayer adapted for precision horticulture: spray patterns and deposition assessments in small-sized citrus canopies, Biosyst. Eng. 113 (1) (2012) 76–85.
[15] R. Sinha, L.R. Khot, G.A. Hoheisel, M.J. Grieshop, H.Y. Bahlol, Feasibility of a solid set canopy delivery system for efficient agrochemical delivery in vertical shoot positioning trained vineyards, Biosyst. Eng. 179 (2019) 59–70.
[16] R.K. Sahni, R. Ranjan, L.R. Khot, G.A. Hoheisel, M.J. Grieshop, Reservoir units optimization in pneumatic spray delivery-based fixed spray system for large-scale commerci al adaptation, Sustainability 14 (17) (2022) 10843.
[17] M.K. Khalil, S.K. Singh, M. Thakre, T. Sahoo, Variability for bunch and berry characteristics in seeded and seedless grape genotypes evaluated under subtropical condition in India, Int. J. Chem. Stud. 7 (4) (2019) 2454–2458.
[18] S. Adarsh, S.M. Kaleemuddin, D. Bose, K.I. Ramachandran, Performance comparison of Infrared and Ultrasonic sensors for obstacles of different materials in vehicle/robot navigation applications, IOP Conf. Ser. Mater. Sci. Eng. 149 (1) (2016), 012141.
[19] M. Kumar, C.R. Mehta, K.N. Agrawal, V.K. Bhargav, V.B. Babu, Spray application characteristics of bio-pesticide solutions through hydraulic nozzles, J. Agric. Eng. 53 (3) (2020) 289.
[20] H. Bijarniya, T.K. Khura, I. Mani, H.L. Kushwaha, S.D. Lande, S.K. Sarkar, Development of liquid urea ammonium nitrate fertilizer foliar application system for enhanced nutrient use efficiency, Indian J. Agric. Sci. 89 (1) (2019) 22–27.
[21] D.B. Smith, S.D. Askew, W.H. Morris, D.R. Shaw, M. Boyette, Droplet size and leaf morphology effects on pesticide spray deposition, Trans. ASAE 43 (2) (2000) 255.
[22] O.G. Oliveira, P.R. Lopes, C.G. Raetano, R.C. Lima, E.P. Prado, Influence of droplet size on spray deposition and weed control using glyphosate, Eng. Agríc. 41 (2021) 449–457.
[23] L. Casanova, R. Casanova, A. Moret, M. Agustí, The application of gibberellic acid increases berry size of" Emperatriz" seedless grape, Span. J. Agric. Res. 7 (4) (2009) 919–927.
[24] T.R. Abu-Zahra, Effect of plant hormones application methods on fruit quality of Superior seedless grape, Biosci. Biotechnol. Res. Asia 10 (2) (2013) 527–531.