

Print ISSN : 0972-8813  
e-ISSN : 2582-2780

[Vol. 22(3) September-December 2024]

# Pantnagar Journal of Research

(Formerly International Journal of Basic and  
Applied Agricultural Research ISSN : 2349-8765)



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## Electrostatic hand sweeper for pest control in cotton crop

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**ABSTRACT:** The electrostatic technology used in agriculture has unique approach to protect the crop from various harmful insects, pest and airborne spores with no negative impact on crop, human health and ecosystem. Three manually hand operated low-cost electrostatic insect sweepers were developed and tested for its bio-efficacy to control whiteflies (*Bemisia tabaci* (Genn.)) and jassid (*Amrasca biguttula biguttula* (Ishida)) in cotton (*Gossypium spp.*) crop. The wire mesh of the insect sweepers is made up of aluminium and stainless steel having good electrical conductivity, which is further connected to electrostatic based generator. This generator helps in the formation of a low resistance path, thereby results in arcing through the body of the insects. The wire mesh periphery is shielded with a poly-vinyl chloride (PVC) insulator. As soon an insect come in touch or pass through the screen mesh, a high voltage produces an electrostatic force without discharging of the spark, which further electrocuted insect's body. Maximum whiteflies reduction of electrostatic insect sweeper is found to be 62.21-% followed by 31.76-% & 20.35-% by in B, C and A respectively after one day of experiment. The highest jassid reduction was found to be 80.42 % for the insect sweeper 'B' followed by insect sweeper 'C' and 'A' which were reduced to be 54.28 and 34.62 %, respectively. Observations reveal that, the percent reduction of whiteflies and jassid by the insect sweeper 'B' was observed significantly higher than the insect sweeper 'A' and 'C'. From this, it was found that the electrostatic hand sweeper was quite efficient and can be utilized as a conservation technique to safeguard the crops against the whitefly for sustainable future agriculture.

**Key words:** Bio-efficacy, cotton, electrostatic, insect, pest, sweeper

Cotton (*Gossypium spp.*) or sometimes American cotton is one of the important crops of Punjab region. American cotton was grown on 2.49 lakh hectares in Punjab during 2021-22. The total production was 6.39 lakh bales with an average yield of 4.36 quintals lint per hectare (1.76 quintals lint per acre) (Anon., 2023). Although cotton is an insect resistant transgenic crop which protects against cotton bollworms, it may get damaged by the sucking pests such as whiteflies, jassid, aphid and mealy bugs. These sucking pests mostly attack the crop between the months of July to September (Abbas, 2018; Kumar *et al.*, 2020a). The whiteflies (*Bemisia tabaci* Gennadius) is one of the top 100 invasive species on the planet (Naveen *et al.*, 2017; DeBarro *et al.*, 2011). As a phloem sap-sucking pest or a vector of viral infections, it has caused serious economic harm to more than 60 crop plants (Naveen *et al.*, 2017;

Kumar *et al.*, 2020b). *Amrasca biguttula biguttula* (Ishida), sometimes known as the cotton jassid, is a leafhopper subspecies belonging to the Cicadellidae family. It preys on okra and other southern Asian crops (Gutierrez *et al.*, 2015). Cotton and vegetables have accounted for more than half of pesticide use in India. Extreme usage of insecticides and pesticides while spraying causes serious health problems to farm workers (Mudereri *et al.*, 2021). Whiteflies have tremendous potential to develop resistance to control insecticides (Naveen *et al.*, 2017; Gutierrez *et al.*, 2015).

In recent research various scientists have direct application of leaf-nesting pests control using a portable electrostatic insect sweeper which to be quite useful (Hamid *et al.*, 1976; Takikawa *et al.*, 2016). Takikawa *et al.* (2015) developed an electric

field screen to control pests and insects. An electrostatic insect-proof screen using an insulated conductor wire using 15 KV DC electrostatic voltage generators was proposed to prevent adult whiteflies (Tanaka *et al.*, 2008). Hamid *et al.* (1976) designed an electronic circuit in such a way that insects drop from the grid due to dehydration. Kakutani *et al.* (2012) made a successful attempt to control pathogens and insect pests affecting tomatoes under changed greenhouse climatic conditions using electric fields. The electric dipolar screen is also considered as a crucial approach for the exclusion of whiteflies with an insulated conducted wire (ICW) charged with an electrostatic voltage generator (Takikawa *et al.*, 2011).

Matsuda *et al.* (2012; 2015) developed a bi-functional electric field screen to physically exclude insect pests from warehouses. This screen consists of insulated iron wires (ICW) arranged in parallel and two earthed conductor nets placed on both sides of the ICW. A negative charge (0.1–8.0 kV) was applied to the insulated wires with a voltage generator to polarize an insulator sleeve used to cover the wire, negatively on the outer surface and positively on the inner conductor wire surface of the sleeve. Larger voltages were necessary to attract much larger insects because larger insects were stronger and therefore moveable to escape from the ICW attraction. Nonomura (2014) used two types of an electric field screen viz., singly charged and doubly charged di-polar electric field to exclude whiteflies. Takikawa (2008) developed a portable electrostatic insect sweeper to capture whiteflies and other insects like jassid. The electrostatic screen was found effective to capture those insects that forcibly push the wind towards the screen as they fly around the screen. Two kinds of electrostatic apparatus i.e., electrostatically guarded nursery cabinet (EGNC) and an electrostatic insect sweeper (EIS) were successfully tested for controlling whiteflies (Kakutani *et al.*, 2017; 2018). A novel electrostatic window screen to prevent mosquitoes from transmitting the Japanese encephalitis virus (JEV) to the surrounding human population to create spore-free and pest-free space in agricultural and horticultural environments but also to purify indoor

air in human domestic environments (Mutsuda *et al.*, 2015; 2018). Matsuda *et al.* (2006) studied the efficacy and successful implementation of spore precipitators in protecting hydroponically cultured tomato plants from powdery mildew in the greenhouse. In spite of capturing the flying insect the electrostatic screen window creates a barrier and is also found very effective for capturing airborne pollen (Takikawa *et al.*, 2017) which can prevent cause of allergic pollinosis.

A number of physical methods have been tested by the various researchers for exploring the possibility of electrostatic devices, screens and screen windows of greenhouses, based on the above discussion, most of the anticipated literature is surrounded across closed greenhouse to prevent the entry of flying insects. The characteristics of anti-insect screens like screen mesh size, electric voltage, effective capturing distance, current and thread diameter were studied by various researchers to determine the effectiveness of screens and to avoid, restrict and capture the entry of bugs in the greenhouse as well as in small open fields crops. Therefore, there is a need to investigate the effectiveness of electrostatic hand sweepers which have the least greenhouse effects and reduce use of agro-chemical and health hazards as compared to conventional alternate practices. However, prevention by electrostatic screens in open fields for cotton crop has not been observed yet. Hence, considering the advantages of electric field screens as environment friendly, the electrostatic hand sweeper has been developed and tested for the control of whiteflies and jassid incidences under open fields in cotton crop.

## MATERIALS and METHODS

**Development electrostatic hand sweeper and working principle:** Three hand operated low-cost electrostatic insect sweepers were developed and test for its bio-efficacy to control whiteflies (*Bemisia tabaci* (Genn.)) and jassid (*Amrasca biguttula biguttula* (Ishida)) in cotton (*Gossypium spp.*) crop. The electrostatic insect sweepers consist of an HDPE frame, three wire mesh, two HDPE insulated spacers of 3 mm thickness, a power supply/ charging circuit,

voltage booster and an oscillator. Appropriate and suitable material may enhance the chargeability of developed insect sweeper screens to trap the insect for longer duration. Electrical conductivity varies for different materials for a fixed applied voltage keeping other parameters constant (Patel *et al.*, 2013). Therefore, right material selection is extremely important to work at lower voltage potential to get best performance. The material of sweeper wire mesh was selected by considering electrical conductivity, weight, resistance against corrosion in harsh environment and cost effectiveness. So far, most frequently and easily available materials were stainless steel and aluminium wire screen and hence were used for the development of electrostatic insect sweeper.

Size of the screen mesh of the electrostatic hand sweeper is selected according to body size of the insect and pests for which it will be used to manage. The size of the screen mesh was selected as most of the insects were not able to pass through it without short-circuiting. The average body size of the insects (i.e., length from head to wingtip, n=20 adults of each species) was  $0.78 \pm 0.09$  mm for the *Bemisia tabaci*,  $3.75 \pm 0.27$  mm (Takikawa *et al.*, 2015) for the green peach aphids,  $3.70 \pm 0.50$  mm for *A. biguttula biguttula*,  $11.46 \pm 0.13$  mm for the Western flower thrips (Takikawa *et al.*, 2016). The developed insect sweeper 'A' has centre screen mesh size of  $6 \times 6$  mm and front and back shields mesh size of  $15 \times 10$  mm. However, the insect sweeper 'B' has all three screen front, centre and back shield mesh size of  $3 \times 3$  mm. And the insect sweeper 'C' has a centre screen mesh size of  $3 \times 3$  mm and front and back shield mesh size of  $3 \times 6$  mm to prevent transition of whiteflies and jassid through the screen. The material of insect sweeper 'A' had all the screen mesh made of aluminium. The front and back net were made of

stainless steel and centre mesh of aluminium for 'B' insect sweeper. All the three screens mesh were made of steel for 'C' hand sweeper. The diameter of 0.9 mm wire was selected for the screen mesh to develop insect sweeper. A 3 mm thick PVC insulated spacer was inserted to maintain the uniform gap between the front and back side of the centre screen mesh in all the developed sweeper. A same capacity 9 Volts alkaline battery was used to provide power for all three insect sweepers. The developed insect sweeper wire mesh screen specification is shown in Table 1.

All three layers were soldered to the wires at the bottom and connected to the output of the voltage booster circuit. To measure the mechanical discharge (an occurrence of electric current), a galvanometer was integrated into a line between screen mesh and voltage generator.

**Working Principle:** The inner layer is connected with the +ve high voltage booster circuit. The outer layers were connected with the -ve terminals of the voltage booster circuit as shown in Fig. 1a and 1b. The current is enabled through an N-P-N transistor which allows the current to flow through a primary coil, inducing voltage in the secondary coil and the secondary coil in return induces a voltage in the feedback coil. This process helps the transistor to conduct again, repeating the process and creating pulsed DC. This voltage is now further boosted using a combination of diodes and capacitors, which is typically a voltage multiplier. The changing magnetic field induces a high voltage in the secondary coil up to 2.5 kV which is sufficient enough to capture the whiteflies. This high voltage is passed into the wire mesh of the electrostatic insect sweeper. Out of three layers of the mesh, the outer two layers are connected to -ve /GND and the inner layer is connected to the generated high +ve voltage as shown in Fig. 1(a) &

**Table 1: Wire mesh size and their materials used in electrostatic insect sweepers**

Insect Sweeper	Battery Used	Screen Mesh size/ materials			Area (mm <sup>2</sup> )	Charging Time (h)	Discharge Time (h)
		Front Mesh (mm)/material	Centre Mesh (mm)/material	Back Mesh (mm)/material			
A	9V (Hi- Watt)	15×10/(Aluminium)	6×6/(Aluminium)	15×10 (Aluminium)	38572	2.35	5.41-5.68
B	9V (Hi- Watt)	3×3/(Steel)	3×6/(Aluminium)	3×3 (Steel)	34542	2.38	5.26-5.40
C	9V (Hi -Watt)	3×3/(Steel)	3×3/(Steel)	3×3 (Steel)	34542	2.30	5.41-5.51

(b). It helps in the formation of a low resistance path, which results in arcing through the body of the insect. A high voltage measuring probe is used to measure the high voltage of insect sweeper just before and after the experiment. Takikawa *et al.* (2015) conducted a lab test assaying the insect capturing capability from 0 to 5.6 kV and observed that the 100 percent whiteflies, western flower thrips and green peach aphid was captured above 1.5kV by the developed device.

**Experimental plan:** To check the bio-efficacy of the designed and developed insect sweepers i.e., 'A', 'B' and 'C' three experimental trials were performed in three different fields of cotton crop at research farm of the Regional Research Station, Abohar, of Punjab Agricultural University, Ludhiana Punjab, India in crop year of 2019-20. The experiment fields

were selected as, where the incidence of whiteflies and jassid above economic threshold level, (6 nos./ 3 leaves) to test the performance of insect sweeper. At the time of experiment plant height of 1000 mm and the number of leaves as 40-50 per plant was observed. The crop planted row to row and plant to plant spacing of cotton crops was 675 mm and 750 mm, respectively as per the local practice of farming adopted by the farmers. Four independent plots are taken to conduct the experiment, one plot for control and three plots for developed three insect sweepers using the total crop area of 200 m<sup>2</sup>. The area of each treatment plot was selected as 50 m<sup>2</sup> (10 m length × 5 m width). The layout of the experiment field is as shown in Fig. 2(A) & (B). Similarly, two more experiments were also conducted to test the bio-efficacy of insect sweeper against whiteflies and jassid control in open fields cotton crop. Before conducting the experiment whiteflies and jassid population were observed to check the population difference in each treatment plot. From the statistical analysis, the whiteflies and jassid population found no significant difference between the treatment plot for the all three treatment of insect sweeper 'A', 'B', 'C' and control at  $p < 0.05$  level of significance. After that sweepers were independently operated in each test plot, operator holds the portable insect sweeper in hand and moves it over and around the canopy to cover entire plant. The operator switches on the 'ON' button of the electrostatic insect sweeper by pressing and holding the button until the completion of treatment in the test plot. After the button is switched 'ON' the electric current starts flowing in an open circuit. Negatively charged conductor and electric field produced by the conductor is simultaneously utilized dielectrically to polarize the wire mesh spacing and the electrostatic field created by the conductor is used to dielectrically polarize the insulator space between the screens. When the whiteflies or jassid comes between the outer and the centre mesh of the sweeper, the electric circuit is completed. Eventually, a high voltage (1.5 - 2.5 kV) passes through the insect body, resulting in the electrocution of the insect body. This process is repeated continuously when an insect comes in contact with the wire mesh and electrocution of the insect body.

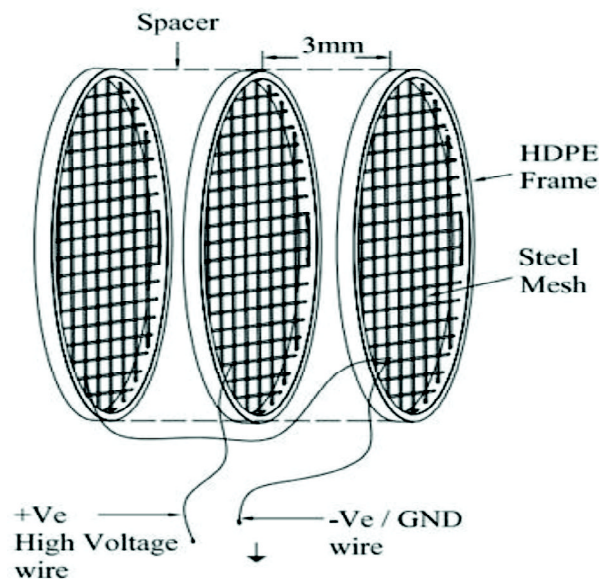


Fig. 1 (a): Schematic arrangement of screen mesh's of developed electrostatic insect sweeper

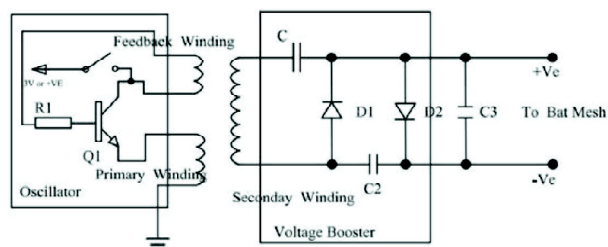


Fig. 1 (b): Circuit diagram of electrostatic insect sweeper to boost voltage

### Observation of whiteflies and jassid population count:

The whiteflies population incidence was observed on twenty numbers of plants randomly selected on each test plot just before and after one day, three and five days of experiment trials. In each test plot six numbers of observations were taken. Numbers of whiteflies adults per three leaves were counted and the mean population of whiteflies was recorded in the datasheet to evaluate the bio-efficacy of developed insect sweeper. The average counts of whitefly adults per three leaves was calculated and employed for comparing and assessing the level of incidence (Kumar *et al.*, 2020c). A similar procedure was adopted to observe the jassid population in each test plot in the same field of experiment in the cotton crop. The field capacity of the developed electrostatics sweeper was determined by calculating the time taken to cover one plant to find the field capacity of the electrostatic insect sweeper. The total number of plants per hectare was calculated by dividing area one-hectare by the area covered by one plant. The cost economics was calculated based on actual privilege wages of labour in the Punjab region.

**Statistical analysis:** The completely randomized block design and general linear model (GLM) were used for the analysis of variance. However, the mean and pair-wise interaction effects on the performance parameters of the electrostatic insect sweeper were compared using Tukey's B post hoc test at a significance level of  $p \leq 0.05$ .

### RESULTS AND DISCUSSION

The test results of all three electrostatic insect sweepers 'A', 'B' and 'C' were analysed. It consists of a charging socket at the bottom of the handle of the sweeper that uses 100-220 V-AC to charge insect sweepers. It takes 3-4 h to get it fully charged and work about 5-6 h effectively. The discharging of the battery depends upon the usage of the sweeper i.e., insects coming in close contact with the wire mesh of the sweeper and thus short-circuiting of insect sweeper circuit. The area of wire mesh screens of sweepers 'A', 'B' and 'C' were calculated as 38572 mm<sup>2</sup>, 34542 mm<sup>2</sup> and 34542 mm<sup>2</sup> respectively. After

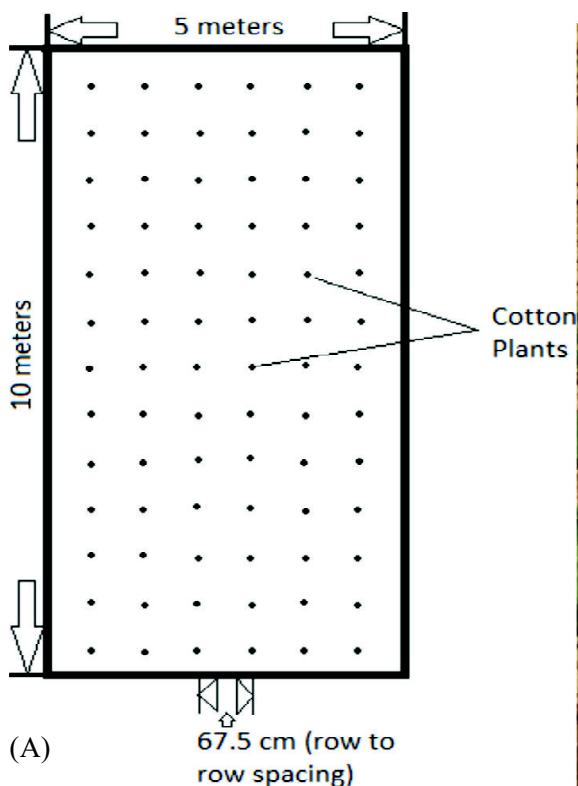


Fig. 2 (A): Layout of experimental field and, (B) testing insect sweeper against whiteflies and jassid in cotton crop

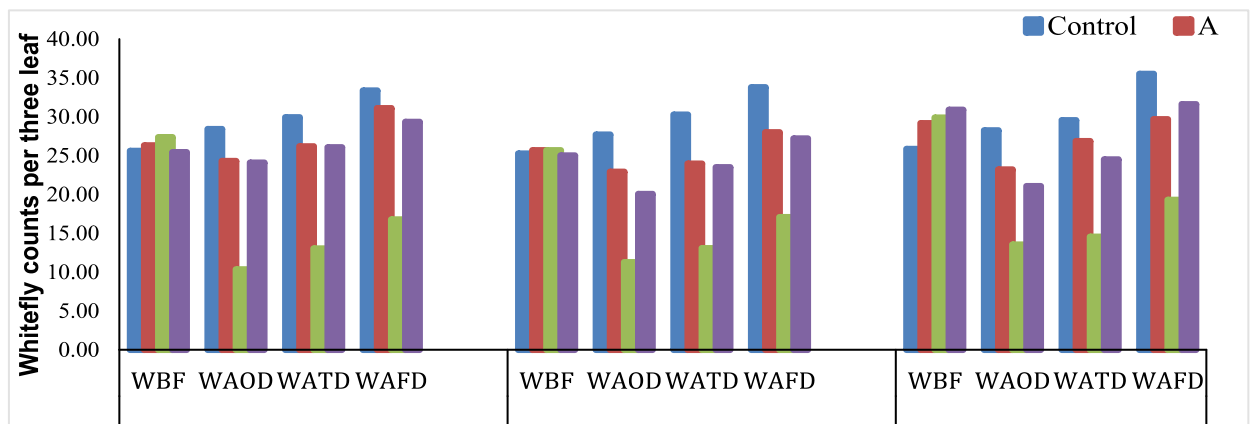
a full charge battery of 9 Volts, the insect sweeper produced 2.5kV maximum which is sufficient enough to electrocute the whiteflies and jassid body. The developed electrostatic insect sweepers work properly when the voltage lies between the 1.5kV-2.5kV. Despite this it was also found that the insect sweeper stops producing electrostatic field in mesh screen when the sweeper voltage falls below the 1.2kV. After preliminary labs test it was found that the insect sweeper works properly and is ready for further testing in actual field conditions to check their bio-efficacy against whiteflies and jassid in the cotton crop. Similarly, Matsuda *et al.* (2011) conducted a test to capture adult cigarette beetles and vinegar flies blown into an electric field screen. The screen's insulated iron wires (ICW) were negatively charged with different voltages. They found that a minimum voltage of 1 kV was required to capture the insects' efficiently.

### Bio efficacy of insect sweepers against whiteflies and jassid:

The field test data of electrostatic insect sweepers were statically analysed and their comparison were made to check bio-efficacy for the control of whiteflies and jassid in cotton crop. Whiteflies count data were observed before the experiments for all test trials to check the variability. From the analysis of variance, no significant difference was found in the population of white flies between the test field. From bar diagram Fig. 3, the

insect sweeper 'B' the number of whiteflies per three leaves in first trail before experiment was observed as 27.39 and reduced to whiteflies after one day, three days and five days as 10.09 (62.21%), 13.06 (52.32%) and 16.79 (38.70%), respectively. Similar trends of insect sweeper 'B' in second trial whiteflies count before as 25.69 and reduction after one day, three days and five days as 11.27 (56.12%), 13.08 (49.09%) and 17.09(33.45%), respectively were observed and third trials whiteflies count before as 29.69 and reduction after one day, three days and five days as 13.57 (54.64%), 14.58 (51.26%) and 19.33(35.40%) respectively, were observed.

From the Fig. 3 insect sweeper 'B' whiteflies count data concentrated more centrally which indicate that it has maximum bio-efficacy to protect the crop as compared to insect 'A' and 'C'. Further if compression is made with the control treatment, the insect sweeper 'B' reduces maximum whiteflies after one day, three days and five days as 63.59, 56.40 and 49.68%, respectively. Nevertheless, the insect sweeper 'C' reduces whiteflies count as 15.26, 12.89 and 12.06% and followed by insect sweeper 'A' which reduces as 14.44, 12.51 and 6.76% after one day, three days and five days respectively of experiment. Similar trend of insect sweeper 'B' of experiment results trials second and third were observed to control maximum whiteflies as compared to 'C' and 'A'. This was due to smaller screen mesh size of 3×3mm of each three screens of



Compariosn of White fly reduction before and after at different trials

Note: Where, WBF, whiteflies count before the test; WAOD, whiteflies count after one day of test; WATD, whiteflies count after Three days of test; WAFD, Whiteflies count after five days of test

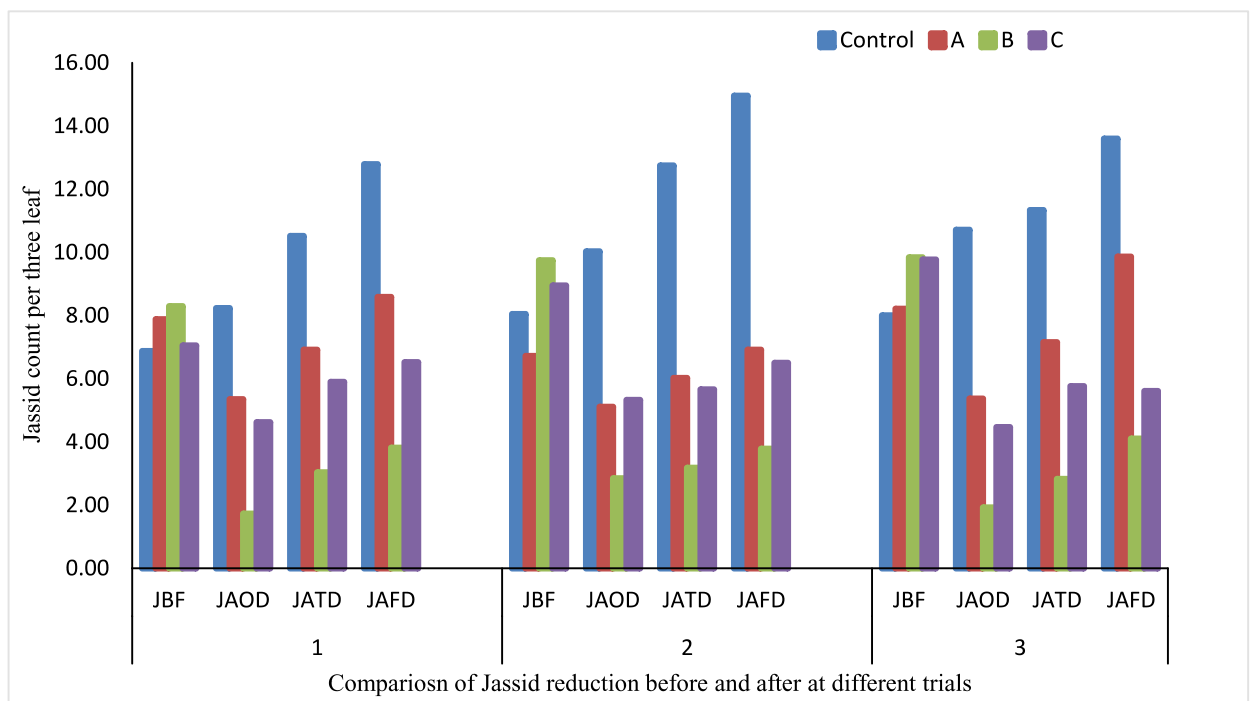
Fig. 3: Performance of different insect sweepers to control whiteflies in cotton crop

insect sweeper ‘B’ which produce uniform electrostatic field inside screen mesh resulting in better electrocution of whiteflies.

It was also observed that after three days of experiment the population of whiteflies increased slightly in all the three trials of experiments. Later on the insect sweepers A and C has no effect on whiteflies population control after five days of experiment because of ‘A’ reduces only 7.54 to 20.35% and ‘C’ reduces only 5.30 to 31.76% whiteflies after one days of test which was not at par sufficient enough to prevent proliferation of whiteflies population with the pass of time. The insect sweeper ‘A’ and ‘C’ have a larger mesh size of screen due to which it has very a smaller amount of white flies control because most of the whiteflies pass through the screen without short circuiting and electrocution. From the analysis of variance, the experiment trials have no significant difference of whiteflies count before and after one, three and five days of experiment. On the other hand, the sweeper has significant differences to control

whiteflies after one, three and five days of experiment. With these results, it is clear that the insect sweeper screen mesh size affects the performance of insect sweeper. Despite this, it is also observed that the interaction effect of trials and sweeper have not significant whiteflies count after one, three and five days of experiments. Tanaka *et al.* (2008) developed a new electrostatic insect-proof screen, called the electric dipolar screen using insulated copper wires charged with opposite voltages to create an electrostatic force. This screen effectively trapped whiteflies and prevented their entry into greenhouses, keeping tomato plants free of whiteflies throughout a 3-week experiment. The mean of different treatments separated with the help of Tukey B test is shown in Table 2 which states that the insect sweeper ‘B’ has significant difference with the insect sweeper ‘A’, ‘C’ and control for the whiteflies count after one, three and five days of experiment.

The Jassid population was counted for all three experimental trials fields before and after one, two and three days of experiments were compared by



**Note:** Where, JBF, Jassid count before the test; JAOD, Jassid count after one day of test; JATD, Jassid count after Three days of test; JAFD, Jassid count after five days of test

**Fig. 4: Performance of different insect sweepers to control the jassid in cotton crop**

using three insect sweepers as shown in bar graph Fig.4. Despite this, control treatment was also used to compare the bio-efficacy of different insect sweeper. The jassid population count data before the experiment was statistically analysed to see the variability between the experiment trails and it was found that there was no statistically significant difference in jassid population was observed in experiment fields to observed difference between the insect sweeper performance at later stage of counting. In third trials the highest jassid population controlled by the insect sweeper 'B' was as 80.42% observed and followed by the insect sweeper 'C' and 'A' having reduction of 54.28% and 34.62%, respectively after one day of experiment as compared to before and after experiment with the treatments. Similar trend of jassid population reduction with insect sweeper 'B', 'C' and 'A' in trial first and second which were observed as 79.17%, 34.41% and 32.09%: 70.73%, 40.49% and 24.01%, respectively as compared to before and after one days of experiments. Whereas, the insect sweeper 'A' after five days have no control of jassid in all the experiments. Although the maximum reduction of jassid population was observed in experiment three with insect sweeper 'B' as 82.01%, 75.01% and 69.78% after one, three and five days respectively and in experiment two 79.01%, 71.14 and 70.15%; and in third which was as 71.56%, 75.05% and 74.70%, after one, three and five days, respectively as compare to control treatment.

However, the jassid population reduction in first, second and third trials was observed for the insect sweeper 'A' as 34.94, 34.28 and 32.82%; 49.07, 52.76 and 53.79%; and 49.87, 36.86 and 27.47%

after one, three and five days respectively, as compare to control treatment. Although the insect sweeper 'C' reduced jassid population in first and second and third trials were 43.79, 43.88 and 48.98%; 46.89, 55.57 and 56.57%; 58.30, 49.15 and 58.78%, respectively. From the comparison of 'A' 'B' and 'C' treatments with the control treatment there was no specific pattern observed to control the jassid. While insect sweeper 'B' is observed with maximum jassid reduction for all the three trials of experiments.

However, the percent jassid reduction by the insect sweeper 'B' was also found as 83.92 percent followed by the 'C' and 'A' having values of 59.73 and 34.81 percent, respectively. However, before and after the test, jassid population was compared and a similar trend was observed for the second and third trial. The higher percent reduction of insect sweeper was due to smaller screen mesh size and larger body dimension of jassid.

The mean of different treatments separated with the help of Tukey B test is shown in Table 2 which is stated that the treatment of insect sweeper 'B' have significantly difference with the insect sweeper 'A', 'B' and control for the jassid control after one, three and five days of experiment. In spite of the insect sweeper, 'A' and 'C' did not differ significantly after one, three and five days after the test. From ANOVA the number of white flies reduced by insect sweeper 'B' is found significantly higher as compared to the insect sweeper 'A' and 'C', whereas insect sweepers 'A' and 'C' were found non-significant at  $p < 0.05$ . It was also observed that the white flies' population reduced by the insect sweeper 'B' was found

**Table 2: Mean and standard deviations of whiteflies and jassid count before, after the experiment**

Type of Sweeper	Whiteflies/3 leave				Jassid/3 leave			
	Before test	After one day of test	After three days of test	After five days of test	Before test	After one day of test	After three days of test	After five days of test
Control	25.58±4.89 <sup>a</sup>	28.12±4.13 <sup>c</sup>	29.93±4.00 <sup>c</sup>	34.23±3.94 <sup>c</sup>	7.6467±1.87 <sup>a</sup>	9.66±2.46 <sup>c</sup>	11.53±2.58 <sup>c</sup>	13.78±2.71 <sup>c</sup>
A	27.06±6.11 <sup>a</sup>	23.49±4.77 <sup>b</sup>	25.13±5.26 <sup>b</sup>	28.83±4.40 <sup>b</sup>	7.6106±2.19 <sup>a</sup>	5.28±1.78 <sup>b</sup>	6.69±1.34 <sup>b</sup>	7.45±1.92 <sup>b</sup>
B	27.66±8.12 <sup>a</sup>	11.73±2.67 <sup>a</sup>	12.90±2.55 <sup>a</sup>	16.21±2.42 <sup>a</sup>	9.2983±2.55 <sup>a</sup>	2.17±0.83 <sup>a</sup>	3.02±0.89 <sup>a</sup>	3.90±1.32 <sup>a</sup>
C	27.12±9.39 <sup>a</sup>	21.74±8.00 <sup>b</sup>	23.04±6.08 <sup>b</sup>	26.35±6.64 <sup>b</sup>	8.595±1.85 <sup>a</sup>	4.8±1.14 <sup>b</sup>	5.77±2.20 <sup>b</sup>	6.37±2.27 <sup>b</sup>

*Note:* Superscript letter represents factor mean within column followed by same letter in caption are not significant different at  $p < 0.05$ . However superscript letter different in caption represent differ significantly at  $p < 0.05$  according to Duncan test.

significantly different as compared to insect sweeper 'A' and 'C'. The Insect sweeper 'A' and 'C' have not a significant difference between each other.

The ANOVA analysis it is observed that the sweepers reduced a significant amount of the jassid population after one, three and five days of experiment at  $P < 0.05\%$  level of significance. It was also observed that the interaction of sweepers and trials have not significant difference to the jassid control after one, three and five days of the test.

**Usage economics of developed electrostatic sweeper in cotton field:** The time taken by sweepers to cover the cotton plant varied depending upon the canopy plants and growth stage of the plant. The time required to cover a plant was found to be 27.5, 30.0 and 27.5 s per plant for the insect sweeper 'A', 'B' and 'C', respectively for whiteflies as well as jassid control in cotton crop. From the ANOVA analysis of variance, it is found that the time required to cover one plant by the insect sweeper has a non-significant difference. Hence the average time taken by insect sweeper per plant is 28.33 seconds. In Punjab cotton is grown row to row and plant to plant spacing of 675×750mm. The area covered by one plant is 0.51 m so the total number of plants per hectare is 19753.08. The total time required to cover one hectare is 147.50 man-hours. Considering working time as 8 hours per day, the wages of labour are taken as per privilege rate of ₹ 360.00 per day. So, the rupees cost of operation is ₹ 6637.50 per hectare. The cost of economics to use an electrostatic device is higher but it has several advantages i. e., reduces chemical pesticide use, reducing environmental impact and harm to beneficial insects while enhancing pest control efficiency. Although the initial cost may be higher, it lowers overall pest management expenses because it is reusable, supports sustainable practices and improves crop quality, yield and safety of farm workers. However, in future there is a need to develop a large U shape drag type device to cover the entire row in a single pass which will definitely improve work capacity to make it cost effective along with bio-efficacy to capture different pest insects in different crops.

## CONCLUSION

In this study, possibilities of an electrostatic eco-friendly technology to control whiteflies and jassid in cotton crops was discovered. The insect sweeper reduces the whiteflies and jassid efficiently when the voltage of screen mesh lies between 2.5 to 1.5kV below 1.2kV it stops to trap insects. Maximum whiteflies reduction was found to be 62.21 % in electrostatic insect sweeper 'B' followed by 31.76 % and 20.35 % by insect sweeper 'C' and 'A' respectively after one day of experiment. The highest jassid reduction was found to be 80.42 % for the insect sweeper 'B' followed by insect sweeper 'C' and 'A' which were reduced to be 54.28 and 34.62 %, respectively. From the analysis, it was observed that the insect sweeper 'B' has significantly higher white flies and jassid population reduction as compared to 'A' and 'C'. The time required to cover one-hectare crop area is 147.5 man-hours which is quite significant to proposed inset sweepers. Correspondingly the total cost of labour per hectare is calculated as ₹ 6637.50/- which is more beneficial as compared to other options like chemical control methods. Furthermore, this proposed technology provides a wide alternative option with several advantages along with human health to protect crops from different harmful insects and pests.

## ACKNOWLEDGEMENTS

This research was supported by the Department of Farm Machinery and Power Engineering, PAU Ludhiana. We are thankful to the Department of Farm Machinery and Power Engineering, PAU Ludhiana for providing a facility for conducting the research.

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Received: September 01, 2024  
Accepted: December 19, 2024