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The effectiveness of four sprayer types to control Alternaria leaf spot disease of cucumber using Rovral TS (Iprodione 35% + Carbendazim 17.5%) fungicide under greenhouse conditions

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Abstract

Cucumber is a significant crop in Iran, where Alternaria leaf spot can be a serious disease if not effectively controlled. This study evaluated the efficacy of four sprayer types in applying Rovral-TS fungicide (Iprodione 35% + Carbendazim 17.5%) against cucumber Alternaria leaf spot disease under commercial greenhouse conditions. The field assay was arranged as a factorial experiment using a randomized complete block design in four replications. Sprayer efficiency was assessed by physical evaluation, measuring solution consumption, and analyzing droplet deposition on sensitive cards placed on cucumber plants. Disease severity was rated before spraying and then at 3, 5, and 7 days after application; the resulting data were statistically analyzed. The results indicated that the 100-liter trolley sprayer used the highest volume of solution (603 L/ha), while the electrostatic atomizer used the least (195 L/ha). Physical assessment revealed that both the standard back atomizer and the electrostatic atomizer achieved better droplet deposition on plants with reduced drift compared to other sprayers. Although there was no significant difference in the disease severity index, the electrostatic atomizer achieved the lowest disease severity at 33.83%. Followed by the trolley sprayer (34.99%), the atomizer with a head (36.39%), and the atomizer with a standard head (37.50%). These results indicate that the electrostatic sprayer improves deposition of spray particles on the target plant through controlled droplet application, enhances spraying efficiency, and minimizes drift.

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Introduction

Protected cultivation offers a controlled environment that mitigate the effects of adverse weather conditions (Yusuf et al., 2025). Greenhouse cucumber cultivation holds significant importance in Iran, and its cultivation area is annually increasing. The greenhouse environment, due to its enclosed nature and high relative humidity, provides a suitable setting for the proliferation of various plant pathogens (Lahlali et al., 2024; Omid & Shafaei, 2005). Globally, in addition to powdery and downy mildews, one of the very important foliar diseases of cucumber is Alternaria leaf spot. In many countries, *Alternaria alternata* (Fr.) Keissl and *A. cucumerina* (Ellis & Everh.) J. A. Elliott have been reported as the main causal agents of cucumber Alternaria leaf spot disease (Vakalounakis & Malathrakis, 1988; Aslan, 2010). In India, Alternaria leaf blight incidence in cucurbits varies among different hosts, with reported losses of 80% in pumpkin and 88% in watermelon and cucumber (Bhargava & Singh, 1985). In Iran, the species *A. tenuissima* (Kunze) Wiltshire has been reported as the predominant species causing cucumber Alternaria leaf spot in East Azerbaijan province, with an incidence of 48% (Eghbali et al., 2017).

Today, extensive global research has been conducted to improve sprayer efficiency, reduce pesticide use, and enhance the deposition of pesticide particles on the target (Shaw, 1982; Kirk et al., 2001). Existing reports indicate significant advancements in the development of electrostatic sprayers due to their numerous advantages (Law, 2001). The deposition of charged droplets from electrostatic sprayers on both the upper and lower leaf surfaces has been studied in relation to voltage, speed, direction and the results showed that droplet deposition on the target surface is greater with electrostatic sprayers (Maski & Durairaj, 2010). Research has demonstrated that in electrostatic sprayers, the force acting on pesticide particles is greater than gravitational force, leading to improved particle deposition on the target and reduced drift (Esehaghbeygi et al., 2010). Reports indicate that approximately 20% of the total sprayed pesticide solution reaches the target, with the remainder being wasted and causing environmental pollution (Sumner et al., 2000). Studies have shown that using electrostatic sprayers for controlling the cotton whitefly increases efficiency and reduces the amount of pesticide used compared to conventional sprayers such as atomizers (Afshari et al., 1998).

An evaluation of microner sprayer efficiency in the chemical control of the wheat bug (*Nysius huttoni* White) demonstrated that this method, in addition to its high efficacy in controlling the pest, can reduce pesticide drift, decrease solution consumption, and minimize crop damage (Sheikhigarjan et al., 2004). The efficacy of electrostatic and knapsack sprayers was compared in combating rice blast disease, and the results showed the electrostatic sprayer had higher efficiency (Heidari et al., 2013). Research suggests that due to reduced pesticide consumption, lower droplet wastage probability, and decreased user contamination risk with back-mounted microner sprayers, they can serve as a relatively suitable alternative to conventional sprayers (Heidari et al., 2013). It has been shown that the application of electrostatic sprayers in controlling cyclamen mite (*Polyphagotarsonemus latus*) on potato was more efficient compared to conventional sprayers (Namvar & Heidari, 2014). In the greenhouses of Iran, there is a difference in terms of the types of pesticides used, application frequency and quantity, and the mixing of fungicides with each other and with insecticides. Residue levels of some insecticides in greenhouse tomatoes and cucumbers have been investigated in the country and, in some cases, reported to be more than national maximum residue limits (Jafari et al., 2004; Imani et al., 2006; Hassanzadeh et al., 2011; Morowati & Azadvar, 2013; Salahi et al., 2013; Morowati & Nematollahi, 2014).

The fungicide Rovral-TS (Iprodione 35% + carbendazim 17.5%) is a systemic fungicide with a 52.5% WP formulation, belonging to the carboxamide family. Its mean lethal dose (LD50) via oral ingestion is 4468 mg/kg, and its Acceptable Daily Intake (ADI) is 0.06 mg/kg/day. The Maximum Residue Limit (MRL) for Rovral-TS in cucumbers is 0.1 mg/kg (Vakalounakis & Malathrakis, 1988). In Iran, the fungicide of Iprodione is common and extensively are being used to control cucumber diseases such as Alternaria leaf spot, Fusarium wilt, and white mold, although it is not registered for control of cucumber leaf spot disease in the country. Given the importance of reducing pesticide use and the role of sprayers in this regard, it is necessary to evaluate both commonly used sprayers and newly proposed ones. Therefore, this research was conducted to find out the most efficient sprayer for controlling cucumber Alternaria leaf spot disease, with an emphasis on reducing fungicide usage on the crop. It was carried out by employing various sprayers under greenhouse conditions to determine the most suitable sprayer.

Material and Methods

This experiment was conducted in a commercial cucumber greenhouse in Agricultural and Natural Resources Research Center, Jiroft, Iran, which had a history of natural infection with Alternaria leaf spot. Each experimental plot consisted of two raised beds (each bed 50 cm wide, containing two planting rows 30 cm apart, with a 5 cm margin on both sides), totaling four 10-meter planting rows with approximately 80 cucumber plants of the RS 189 Sina F1 cultivar (Royal Sluis, Netherlands), a common cultivar in the region, susceptible to the disease. The experiment was carried out in a 500-square-meter greenhouse with plastic covering and a metal frame. In accordance with local practice, the spacing between beds was 80 cm, and the spacing between plants within a row was 45 cm. When disease symptoms were observed on approximately 20 to 30% of the leaves, the spraying operation was conducted in the afternoon of the designated day. The sprayers used were: a back-mounted atomizer with a microner head, a back-mounted atomizer with an electrostatic head, a back-mounted atomizer with a standard head, and a 100-liter trolley sprayer. At the time of spraying, the greenhouse temperature was 25°C with 65% relative humidity. All sprayers were calibrated prior to use. During spraying, the experimental plots were separated from each other by vertical plastic sheets to prevent cross-contamination between treatments. Evaluation of the sprayers was conducted both physically and biologically. Physical Evaluation: For this purpose, the amount of pesticide solution consumed per hectare and the coverage and uniformity of droplet deposition on the target were assessed. To determine droplet coverage and uniformity, water-sensitive cards (Afshari & Bayat Asadi, 1990) were placed on various parts of the plant including the upper and lower leaf surfaces and within the canopy. Then the cards were examined and compared in the laboratory for the uniformity of droplet receipt and coverage.

Biological Evaluation: This section evaluated the effect of different sprayers on controlling cucumber Alternaria leaf spot disease. To assess the efficacy of the sprayers in disease control, a factorial experiment was conducted using randomized complete block design with four treatments and four replications. The first factor included four sprayer types: (a1) atomizer with a standard head, (a2) atomizer with a microner head, (a3) atomizer with an electrostatic head, and (a4) 100-liter trolley sprayer. The second factor was the number of spray applications at two levels: (b1) first application and (b2) second application, carried out two weeks after the first. Sampling and disease rating were performed at times zero (before spraying), and three, five, and seven days after spraying. Disease severity in different treatments was assessed by evaluating six leaves per plant and 10 plants per replication, totaling 240 leaves selected from the lower, middle, and upper sections of the plants for each treatment. The leaves were scored based on the method of Thomas et al. (1987) with some modifications by Nasr Esfahani et al. (2014). The rating was as follows: 0 = leaf without infection, 1 = leaf with negligible infection, 3 = leaf with slight/low infection, 5 = leaf with moderate infection, 7 = leaf with severe infection, and 9 = complete leaf necrosis. In the final evaluation, disease severity index (DSI) was calculated as a percentage using the equation $DSI = \sum(\frac{ni \times vi}{n \times v}) \times 100$. In this equation, DSI = disease severity index%, n_i = number of infected leaves with the same score, v_i = disease score for each leaf, N = total number of leaves evaluated, and V = maximum disease score. Calculations were performed using Excel 2010. Statistical analysis was performed using SAS software version 9, and mean comparison was conducted with the Least Significant Difference (LSD) test at the 5% level.

To determine fungicide residue on the fruit, a one-kilogram sample was randomly collected five days after spraying (accounting for harvesting every 3-4 days and one day for market delivery). After being placed in dark plastic bags under cool conditions, it was transferred to the laboratory for extraction and residue analysis. For the extraction and analysis of Iprodione fungicide residue, 10 grams of the ground fruit sample were placed in a 150 ml beaker, and 60 ml of acetone was added and homogenized for two minutes followed by adding 60 ml of acetone, and were homogenized thoroughly for another two minutes. After filtering the solution using a vacuum pump and filter paper, the filtered solution was transferred to a separatory funnel and 150 ml of a 2% sodium sulfate solution was added to the funnel, followed by 40 ml of dichloromethane, and shaken for one minute. The organic phase (lower phase) was separated, and this step was repeated twice with 20 ml of dichloromethane each time. The contents were passed through a Buchner funnel containing sodium sulfate, and after evaporating the filtered solution at 50°C, one ml of hexane solvent was added and injected into a GC/ECD device for Iprodione measurement. Residue analysis was performed using a Schimadzu GC-ECD-2010 device with a splitless injector at 240°C, nitrogen-air carrier gas, at 100 kPa pressure, a total flow of 40 ml/min, a column flow of 0.74 ml/min, and a Varian CPSIL24CB column 30 meters in length (Morowati and Azadvar, 2013; Tribolet and Gasser, 1995).

Results

Disease Symptoms

The initial symptoms of cucumber Alternaria leaf spot appeared as yellow to light brown spots, 1-2 millimeters in size, on the upper leaf surface (Fig. 1A and 1B). The symptoms typically began on older leaves and gradually progressed to middle-aged and younger leaves, became severe under humid conditions. As the disease advanced, the spots enlarged and concentric brown rings appeared (Fig. 1C).

Physical Evaluation of Sprayers

The results of the sprayer calibration showed that the highest volume of solution consumed by 100 L trolley sprayer, at 603 liters per hectare. The lowest water consumption was observed in atomizer sprayer equipped with an electrostatic head, at 195 liters per hectare. The atomizer sprayer with a standard head (346 L/ha) and the atomizer sprayer with a microner head (280 L/ha) ranked next in terms of water consumption per hectare (Fig. 2).

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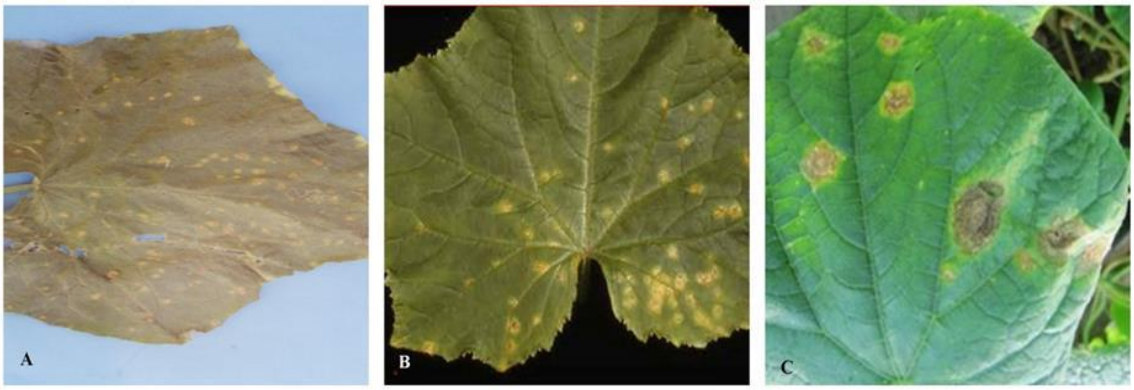

Fig. 1. Symptoms of Alternaria leaf spot on greenhouse cucumber cultivar RS 189 Sina (Royal): early stages (A-B) and advanced stage (C).

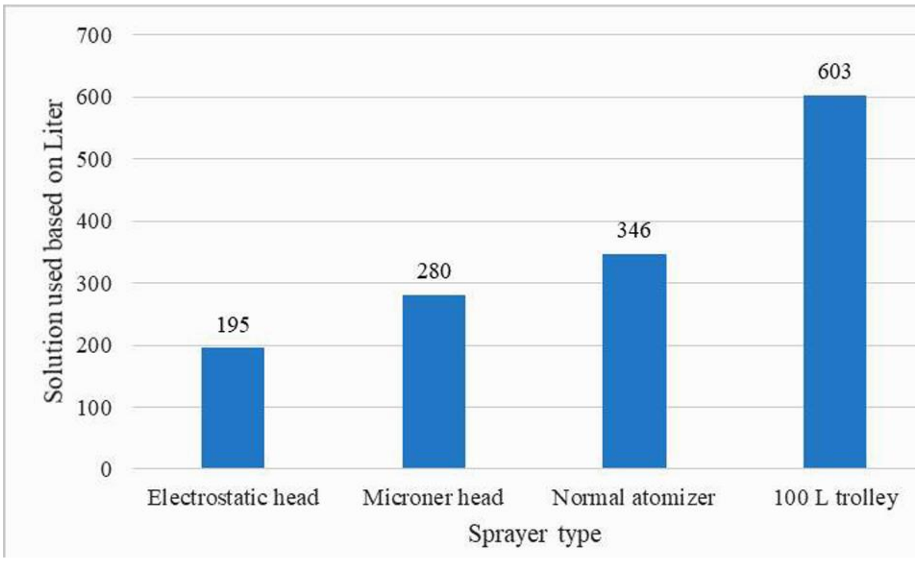

Fig. 2. Comparison the use of fungicide solution per hectare in different sprayers.

The results from analyzing droplets deposited on the water-sensitive cards showed that with 100 L trolley sprayer, 35 to 40 percent of the cards installed on the plants were completely saturated with water droplets. In fact, the merging of water droplets on the card surfaces led to a run-off of the pesticide solution on the cards. Between 10 to 15 percent of the cards received no pesticide droplets, while the remaining cards received droplets of varying sizes, indicating poor spraying uniformity with this type of sprayer. Examining the droplet size and their distribution pattern on the cards was not feasible due to the high droplet density and their coalescence. However, the droplet diameter ranged from 60 to 1000 microner, which indicates the lack of particle uniformity. For the atomizer sprayer with a standard head, spraying uniformity was higher than the trolley sprayer. All cards installed on the upper leaf surfaces and 25 percent of those on the lower leaf surfaces received pesticide droplets. With the electrostatic head sprayer, all cards installed on the leaf surfaces and 50 percent of those on the undersides of cucumber leaves received pesticide droplets. Greater uniformity was observed in the diameter of the generated pesticide particles, with 85 percent of the droplets having a relatively uniform diameter. For the microner head sprayer, a high degree of uniformity was observed in pesticide coverage on cards installed on the leaf surfaces. However, 60 percent of the cards installed on the undersides and within the leaf canopy received no pesticide particles. This is likely due to the small droplet size leading to drift, which consequently reduced pesticide penetration to the middle leaves.

Biological evaluation

The results of the analysis of variance showed that the sprayer type did not have a significant impact on the severity and incidence of cucumber Alternaria leaf spot disease. However, the number of spray applications had a significant effect ($p \leq 0.01$) on the aforementioned traits. Furthermore, the interaction effects between sprayer type and the number of applications also did not have a significant impact on disease severity and control efficacy (Table 1). Results indicated that the type of sprayer did not have a significant effect on disease severity at 3, 5, and 7 days after spraying (Table 2). However, the atomizer sprayer with an electrostatic head performed more favorably than the others. Using this sprayer, the disease severity decreased to 33.83% five days after application. Following this, the trolley sprayer, the atomizer with a microner head, and the standard atomizer showed disease severities of 34.99%, 36.39%, and 37.50% respectively, five days after spraying. Furthermore, the results indicated that treatments with two-time sprays had the lowest disease severity at 5 and 7 days after spraying, with values of 31.30% and 31.84%, respectively (Table 3). The interaction between sprayer type and application timing show that the most favorable treatment was the electrostatic head atomizer sprayer five days after application which reduced disease severity to 27.95%, representing 45% compared to the control. In contrast, the back-mounted atomizer with a microner head, three days after spraying, showed the lowest efficacy relative to the control, with a disease severity of 54.65%. The results of Iprodione fungicide residue on fruit samples five days after spraying showed that the residue amount on cucumber fruit was 1.81 ppm for the electrostatic head atomizer sprayer and 1.68 ppm for the standard atomizer sprayer. In contrast, residue was undetectable for the trolley sprayer, the microner head sprayer, and the control.

Table 1. Analysis variance of the effect of sprayer type and number of spraying on disease severity and control percent of Alternaria leaf spot disease of cucumber.

Source of variations	df	Mean of Squares					
		3 DAS[a]		5 DAS		7 DAS	
		disease severity	Efficiency control	disease severity	Efficiency control	disease severity	Efficiency control
Block	3	39.28 ^{ns}	435*	166.43**	812**	23.61 ^{ns}	313 ^{ns}
Sprayers(a)	3	44.74 ^{ns}	118 ^{ns}	20.63 ^{ns}	79 ^{ns}	8.96 ^{ns}	30 ^{ns}
Number of spraying (b)	1	2469**	6368**	612.50**	1925**	424 **	1358**
Interaction (a*b)	3	31. ^{ns}	79 ^{ns}	15.68 ^{ns}	48 ^{ns}	6.68 ^{ns}	26 ^{ns}
Error	21	48	110	33.83	104	38.657	124
C.V		16		16	29	17	31

^{ns}, **, * = non-significant, significant at 1% and 5% level, respectively, a = days after spraying (DAS).

Table 2. Mean comparison of the efficacy of different sprayers on disease severity and disease control percent of Alternaria leaf spot disease of cucumber.

Sprayer Type	3DAS[a]		5DAS		7DAS	
	Disease severity	Control percent	Disease severity	Control percent	Disease severity	Control percent
A1	46.15 ^{a}	17.37 ^{a}	37.50 ^{a}	31.25 ^{a}	35.74 ^{a}	34.64 ^{a}
A2	45.04 ^{a}	20.85 ^{a}	36.39 ^{a}	33.40 ^{a}	35.90 ^{a}	34.44 ^{a}
A3	41.10 ^{a}	26.62 ^{a}	33.83 ^{a}	38.54 ^{a}	33.95 ^{a}	37.78 ^{a}
A4	42.2 ^{a}	22.59 ^{a}	34.99 ^{a}	35.94 ^{a}	36.36 ^{a}	33.21 ^{a}
LSD (0.05)	7.25	10.94	6.05	10.62	6.46	11.59

A1 = standard sprayer, A2 = atomizer with a microner head, A3 = atomizer with an electrostatic head, and A4 = 100 L trolley sprayer. a = days after spraying (DAS). Means within each column followed by same letter are not significantly different.

Table 3. Mean comparison of the effect of spraying numbers on disease severity and control percent of Alternaria leaf spot of cucumber.

Spraying number	3DAS[a]		5DAS		7DAS	
	Disease severity	Control percent	Disease severity	Control percent	Disease severity	Control percent
1st spraying	52.40 [a]	7.75 [b]	40.05 [a]	27.02 [b]	39.13 [a]	28.50 [b]
2nd spraying	34.84 [b]	35.97 [a]	31.30 [b]	42.54 [a]	31.84 [b]	41.52 [a]
LSD (0.05)	5.13	7.73	4.28	7.51	4.57	8.2

Means within each column followed by same letter are not significantly different. a = days after spraying.

Discussion

Although there was no significant difference in disease severity index, but it was found that there is significant variation in terms of total solution volume used among the tested sprayers, underscoring the critical role of application technology in total fungicide consumption. The superior disease suppression observed with (specify best-performing sprayer type, e.g., the electrostatic) is likely attributable to its enhanced canopy penetration and superior foliar coverage, which optimized the deposition and distribution of the Rovral TS (Iprodione + carbendazim) formulation. This result aligns with the established principle that efficient disease management under protected cultivation relies not only on fungicidal potency but also on the precision of delivery, which directly influences the chemical's contact with the pathogen. Greenhouse cultivation is essential for increasing crop production and providing a stable food supply, especially in areas with harsh climates. These controlled environments also will provide a suitable condition for incidence of fungal disease, so it needs to use effective and innovative control measures. In this study the results of calibration of sprayer indicated that the 100-liter trolley sprayer used the highest volume of solution (603 L/ha), while the electrostatic atomizer used the least (195 L/ha). The results of previous experimental work showed that the volume of solution used in electrostatic and microner sprayers is generally less than 100 liters per hectare (Afshari et al., 1998; Heidari et al. 2013). The total volume per hectare of solution used in this experiment was slightly higher than the results reported by other researchers. It seems this discrepancy in consumption volume is related to the use of a dedicated electrostatic base sprayer unit, which was not employed in this experiment. Here, only an electrostatic head mounted on an atomizer sprayer was used. However, greenhouse conditions, plant growth stage (canopy), and host type also influence the amount of pesticide solution consumed. From a physical evaluation perspective, in the atomizer sprayer with a standard head, pesticide droplets were primarily deposited on the plant, showing less drift compared to microner and trolley sprayers (based on the residue measurement and droplet deposition on plants), with most droplets concentrated on the plant. The assessment of sensitive cards for the microner sprayer, and the absence of droplets on some cards installed under and within the plant canopy, indicate drift of the pesticide to non-target areas. The likely cause is an excessive reduction in droplet size. Our results showed that the sprayer with the electrostatic head had the lowest amount of pesticide wastage (based on the card analysis), and almost all droplets were deposited on the plant (increased deposition on the crop). Therefore, this method can achieve acceptable disease control even by reducing the applied dose. This allows for a reduction in pesticide use while largely preventing drift, and enables effective application with doses below those of standard spraying. Although the analysis of variance did not reveal a significant difference between the sprayers, but the mean comparison of disease severity across different sprayers showed that the electrostatic head atomizer sprayer had the better efficacy in controlling cucumber Alternaria leaf spot disease. The results indicated that deposition on the primary target (the plant) was better with the electrostatic and standard head atomizer sprayers, and given their equal efficacy, they can be recommended due to reduced pesticide consumption. The mechanism of droplet generation and the ability to penetrate into the middle sections of the plant are among the factors contributing to this reported efficacy (Heidari et al., 2013). The results of this research indicate that for disease control, a minimum of two spray applications, spaced no more than one week apart, is necessary. The results show that the electrostatic sprayer, due to its lower solution consumption volume and higher efficacy in controlling cucumber leaf spot disease, can be prioritized in disease management programs. Although the trolley sprayer did not show a significant difference in disease control compared to others, it is not recommended due to its high pesticide consumption per hectare and the higher labor costs associated with moving the hose. The optimal period for the pesticide's effect on the disease is five to seven days after application.

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Conflict of interest

The authors disclose that there is no conflict of interest.

CRediT author statement

M. Najafinia: Supervision, Writing, Funding acquisition. **A. Heidari:** Laboratory work, technical assistance. **M. Morowati:** Data curation, formal analysis, visualization.

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