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Research Article

Optimal efficacy of the essential nozzle characteristics and insecticide type for controlling cabbage aphid

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Abstract: The previous works have addressed selecting the nozzle to minimize the hazard of pesticide drift by producing large spray droplet sizes. However, this spray application with the largest sizes does not effectively impact insects either, as it needs many pesticides. Several studies have demonstrated that the small spray droplet sizes can affect the insects and be obtained by selecting the appropriate nozzle size and height. This study sheds light on the nozzle sizes and heights, and insecticide types for controlling the cabbage aphid to ensure efficient insect control. Different parameters including three sizes of flat fan nozzle 01, 02, and 03, two nozzle heights 35 and 70 cm above the plant top, and two insecticide types 20% wide plus WP and 90% methomyl SP were investigated to measure spray deposition, coverage percentage, and droplets density in different locations of the cabbage plant for improving control efficacy. The outcomes showed significant differences in the spray deposition and coverage percentage using different nozzle sizes, nozzle heights, and insecticide types. The best spray deposition, coverage percentage, and control efficacy (0.321 $\mu m.cm^{-2}$, 15.05%, and 84.83%, respectively) were achieved using the 02 nozzle size, nozzle height of 35 cm methomyl SP insecticide type on the fourteenth day after spraying application in comparison to the others. The fourteenth day was the most effective to control aphids compared to the first and the seventh days.

Keywords: spray deposition, coverage percentage, nozzle size, control efficacy, aphid

Introduction

Cabbage *Brassica oleracea* is a crucial vegetable plant in Iraq and other countries in total production (Karungi *et al*., 2008; FAO, 2003). The high quality and yield of cabbage significantly differ based on various factors such as cultivating type, variety, weather conditions, and plant protection from diseases during the growth period until marketing (Shrestha, 2016). Although the weather conditions during the cabbage growing season, such as sunlight, rainfall, cold, and moisture, play an essential role in cabbage cultivation and yield (Nurhidayati *et al*., 2016; Paranhos *et al*., 2016; Tanyi *et al*., 2018), these conditions encourage some insects as aphid to attack cabbage plant. These insects affect the cabbage plant at different locations, especially in the upper layer, and consume the nutrients, leading to yield reduction and quality depreciation (Altieri *et al.,* 2005). Therefore, the control of the aphid is a critical and vital issue. In Iraq, the occurrence of cabbage aphid is most common (Singh and Singh, 2015). Recently, farmers worldwide use modern technologies in pesticide spraying to control insects

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(Mengistie *et al*., 2017). Whereas the Iraqi farmers usually utilize the knapsack sprayers (Alheidary, 2017). In general, the selection of favorable operating conditions for sprayers such as nozzle type, nozzle size, and nozzle height is essential to improve the control (Wolf and Daggupati, 2009; Foque and Nuyttens, 2011; Wang *et al*., 2020). It is noteworthy that reaching and penetrating a sufficient amount of pesticide into the plant relates to the appropriate nozzle size and height, increasing spray droplet coverage and deposition on the intended target (Zhu *et al*., 2008; Alheidary, 2018; Chen *et al*., 2020). Also, the nozzle size is considered a limiting factor for application rate and spray droplet size (Wang *et al*., 2019). Several studies confirmed minimizing the hazard of pesticide drift by producing large spray droplet sizes without regard to the control efficacy on the insects (Alheidary *et al*., 2014; Cunha *et al*., 2017). The insects can be affected by small droplet sizes, depending on the nozzle size and height (Boina *et al*., 2012). On the other hand, another significant factor in insect control is the formulation of insecticide type (Chen *et al*., 2020; Zhang *et al*., 2020). To ensure more efficacious insect control, the main goal of this study focuses on the effect of nozzle sizes and heights and insecticide types for controlling aphids in cabbage.

Materials and Methods

Field experiments

The field experiments were performed in the Agricultural Researches Station, College of Agriculture, University of Basrah (30.561821” N, 47.751860” E). A hybrid variety of cabbage was cultivated on September 8, 2019, and the planting density was 31746 plants.ha^{-1}. The insecticides were sprayed at the time of aphid appearance (October 10, 2019), when the average cabbage height was approximately 20 cm and the leaf area index was 1.5.

Two types of insecticide, 20% wide plus wettable powder and 90% methomyl sp were used at concentrations 0.5 g.l^{-1} and 0.25 g.l^{-1} respectively. The main properties of insecticides are represented in Table 1.

Table 1 Main properties of the insecticide types.

Trade name	Active ingredients	Spray calibrated (g.l^{-1})	Actual dose recommended (g.100l^{-1})	Producer company
Wide Plus 20%	Acetamiprid 20%	0.50	50	Shenzhen Cropstar Chemical Industry
Methomyl 90%	Methomyl 90%	0.25	25	Rinchen Industrial China LTD.

Sprayer and nozzle characteristics

All spraying experiments were performed using a knapsack sprayer (Jagatsukh Industries Co.) (Fig. 1).

The characteristics of this sprayer are shown in Table 2.

For the nozzle characteristics (Table 3), three nozzle sizes 01, 02, and 03 of the flat fan type were selected in this study at the same angle (110º) of the spraying. Each nozzle size was investigated with two heights (35 and 70 cm). Also, nozzle flow rates were calculated at an operating pressure of 2 bar based on the application rate (Table 2) according to equation 1:

$$Q = \frac{q \times 600}{v \times D} \quad (1)$$

Where Q is the application rate (l.ha^{-1}); q: is the nozzle flow rate (l.min^{-1}); V is the worker speed (0.28 km.hr^{-1}), and D is the spraying width (m).

Field experiments

The field experiments were carried out on October 10, 2019, using two types of insecticide at different treatments (20% wide plus wettable powder and 90% Methomyl sp) for spraying processes to control the cabbage aphid. As shown in Table 4, 20% wide plus wettable powder was added into the treatments 1, 2, 3, 4, 5, and 6 as well as, 90% Methomyl sp was added into treatments 7, 8, 9, 10, 11, and 12. In addition, the control treatment (13) contained water with 1 g.l^{-1} of the Brillant Solfa Flvine (BSF) tracer without any insecticide.

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Figure 1 Side view of knapsack sprayer.

It is noteworthy; all these treatments were distributed according to the nozzle sizes and nozzle heights. Each treatment was repeated three times, as explained in Table 4. Then the average of these repeats was separately calculated.

The field experiments included measuring the spray droplets' characteristics such as deposition, coverage percentage, size, density, and distribution.

Table 2 Characteristics of the knapsack sprayer.

Specification	Values
Model	XF-16B
Total empty weight (Kg)	3.4
Operating method	Manual action
Tank capacity (L)	16L
Range of the operating pressure (bar)	2-4
Nozzle numbers	1
Spraying width (m)	Depending on the nozzle height & type
Worker speed ($m.sec^{-1}$)	1.03
Application rate ($l.ha^{-1}$)	Depending on the nozzle mounted

Table 3 Nozzle characteristics.

Nozzle type	Nozzle size	Nozzle angle°	Nozzle height (cm)	Nozzle color	Nozzle flowrate ($l.min^{-1}$)	Application rate ($l.ha^{-1}$)
Flat fan	01	110	35 and 70	Red	0.25	121.36
Flat fan	02	110	35 and 70	Yellow	0.48	233.01
Flat fan	03	110	35 and 70	Blue	1.04	504.85

Table 4 Characterization of the field experiments.

Treatment number	Zone	Nozzle height (cm)	Nozzle size	Insecticide type
1	A	35	01	20% wide plus wettable powder
2	A	35	02	20% wide plus wettable powder
3	A	35	03	20% wide plus wettable powder
4	B	70	01	20% wide plus wettable powder
5	B	70	02	20% wide plus wettable powder
6	B	70	03	20% wide plus wettable powder
7	C	35	01	90% Methomyl sp
8	C	35	02	90% Methomyl sp
9	C	35	03	90% Methomyl sp
10	D	70	01	90% Methomyl sp
11	D	70	02	90% Methomyl sp
12	D	70	03	90% Methomyl sp
13	E	(35, 70)	(01-02-03)	Water only with BSF (control)

Measurement of the deposition and coverage percentage

Three Water paper cards (WPCs) were positioned on the plant at equal heights (upper, middle, and bottom) (Fig. 2).

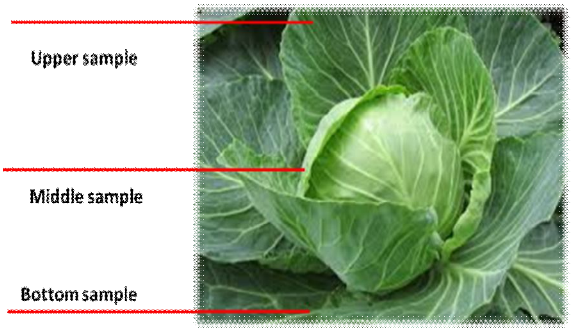

Figure 2 Positions of the water paper cards on the plant.

When the spray droplets were deposited on the WPCs, they left yellow spots due to the added BSF tracer. Then, the WPCs were carefully collected with a clean hand after the field experiment had finished. After that, when these cards completely dried, they were placed in a self-sealing container. For the WPCs analysis, at first, an HP scanner was used to scan them at a resolution of 600 dpi, then the ImageJ software was used to obtain findings of the spray droplets characteristics.

Control of the cabbage aphid

Before applying the insecticides, the number of living aphids was counted under the dissecting microscope. After that, they were sprayed with the thirteen treatments mentioned in Table 4 applied in the cabbage field, which was surveyed to check the controlling of aphid using a counting number method per cm^{-2}. In this method, the three plant positions (upper, middle, and bottom) and three random places from each field experiment zone were considered. The following equation was used to calculate the decrease rate of aphid during 1^{st}, 7^{th}, and 14^{th} days after spraying.

$$Dr(\%) = \frac{N_b - N_a}{N_b} \quad (2)$$

Dr: is the decrease rate of aphids, Nb: the number of living aphids before spraying, and Na: the number of surviving aphids after spraying.

Then, the control percentage was calculated using the following equation:

$$E\% = \frac{D_{r1} - D_{ro}}{100 - D_{ro}} \quad (3)$$

E is the control percentage, Dr_1 is the decreasing rate of aphids, and Dr_0 is the decreasing rate of aphids in treatment number 13.

Metrological conditions

In the field, the metrological conditions, including air temperature, relative humidity, and wind speed, were measured on the same day for all treatments using an anemometer (Model MS 6253B with an accuracy of ± 0.02). Data of these measurements are shown in Table 5.

Statistical analysis

The findings of this study were statistically analyzed using ANOVA, and the average of each treatment was separately calculated at $P < 0.05$. The significant differences among the values were evaluated using the least mean square (LSD) at the level of 5%.

Table 5 Data of the metrological conditions.

Number of the experiment	Mean air temperature (℃)	Mean relative humidity (%)	Mean wind speed ($m.sec^{-1}$)
1-13	32	30	5.03

Results

Characteristics of the spray droplets

The results of WPCs scanning revealed a significant effect of nozzle sizes and heights on the distribution ($D_{v0.1}$, $D_{v0.9}$, and $D_{v0.5}$) of the droplets deposited at different layers of the cabbage plant (upper, middle, and bottom), as shown in Fig. 3 and Table 6. Interestingly, the $D_{v0.5}$ was recorded 279, 267, and 223 µm at the three layers, respectively, using flat fan 02 compared to the others.

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Table 6 Impact of nozzle sizes and heights on the spray droplet characteristics.

Nozzle type	Sample location	Nozzle height cm	Dv0.1 µm	Dv0.5 µm	Dv0.9 µm	RSF
FF 01	Upper	35	127	213	530	1.89
FF 01	Upper	70	184	197	1052	4.41
FF 01	Middle	35	119	195	491	1.91
FF 01	Middle	70	167	163	456	1.77
FF 01	Bottom	35	109	164	479	2.26
FF 01	Bottom	70	151	103	489	3.28
FF 02	Upper	35	196	289	673	1.65
FF 02	Upper	70	224	277	985	2.75
FF 02	Middle	35	189	287	980	2.76
FF 02	Middle	70	191	254	937	2.94
FF 02	Bottom	35	152	268	872	2.69
FF 02	Bottom	70	159	229	684	2.29
FF 03	Upper	35	249	285	918	2.35
FF 03	Upper	70	305	213	1041	3.46
FF 03	Middle	35	221	203	629	2.01
FF 03	Middle	70	235	178	921	3.85
FF 03	Bottom	35	206	236	930	3.07
FF 03	Bottom	70	218	217	941	3.33

Dv0.1: indicates that 10% of the spray volume are smaller droplets than this value; Dv0.9: indicates that 90% of the spray volume are smaller droplets than this value; Dv0.5: indicates that half of the spray volume is smaller droplets than this value.

RSF: indicates the uniformity in the distribution of droplet sizes and the variation among the droplets. As well, it is related to the spray deposition and drift potential and can be calculated according to (Dv0.9-Dv0.1)/Dv0.5

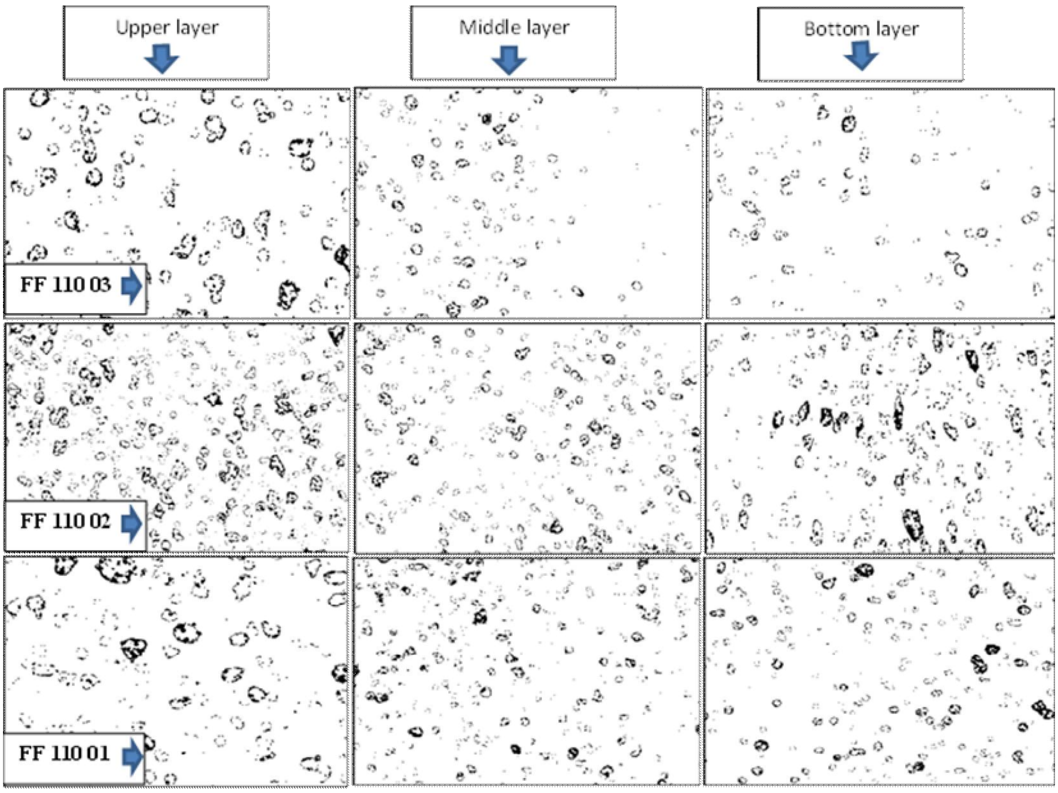

Figure 3 Deposition of the droplets on the water paper cards at three layers of the cabbage.

Higher droplets deposition was observed on the upper layer of the plant compared to others layers. Table 6 shows that spraying with the nozzle size 02 resulted in high droplets deposition at different layers, especially on the upper layer, compared to the other nozzle sizes. Also, when the nozzle size 02 was used, the relative span factor (RSF) was closer to 1.

The effect of nozzle heights was also evaluated, and significant differences appeared in the droplets deposition on the different layers of the plant. Best droplet characteristics, lower values of CV (coefficient variance), and best RSF values were observed with the nozzle height 35cm comparing to 70 cm.

Spray droplets deposition

In general, spray droplet deposition is inversely correlated with volume median diameters. Figs. 4 and 5 show significant differences ($P < 0.002$) in the spray deposition on the cabbage plant involving several deposited droplets (droplets. cm^{-2}) and the number of deposited droplets (µl. cm^{-2}). Higher values of the number and the amount of spray deposition (102.9 droplets.cm^{-2} and 0.766 µl.cm^{-2} respectively) were obtained on the upper layer using nozzle size 02 and height of 35 cm in comparison to others. While on the bottom layer, there were no significant differences in spray deposition for all nozzle sizes and heights. When the nozzle sizes and heights were changed, the deposition peaks shifted toward the left of the curve.

Spray coverage percentage

The correlation between spray coverage percentage and the volume median diameters was also reverse. Fig. 6 illustrates significant differences ($P < 0.0025$) in spray coverage percentage due to the influence of nozzle sizes and heights. The highest values of spray coverage percentage (10.49%, 9.33%, and 6.22%) appeared on the upper, middle, and bottom layers, respectively, using the nozzle size of 02. The results also indicated that the peaks of coverage percentages shifted to the left of the curve due to the nozzle sizes and heights. It is noteworthy that the spray coverage percentage was the greatest (18.83%) using 02 nozzle size and 35cm nozzle height comparing to the others.

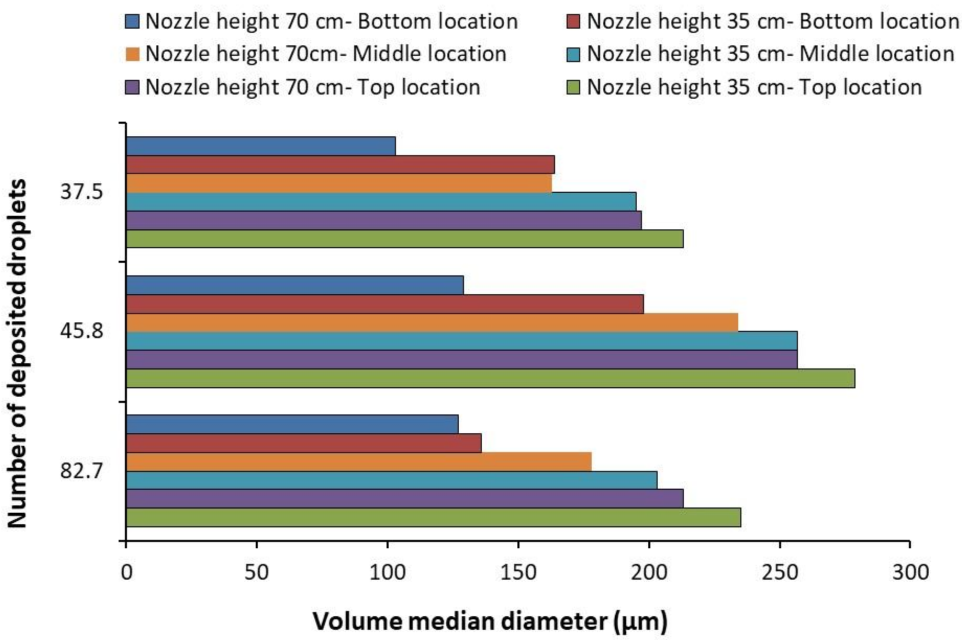

Figure 4 Correlation between spray deposition and droplet diameter at different nozzle sizes and heights.

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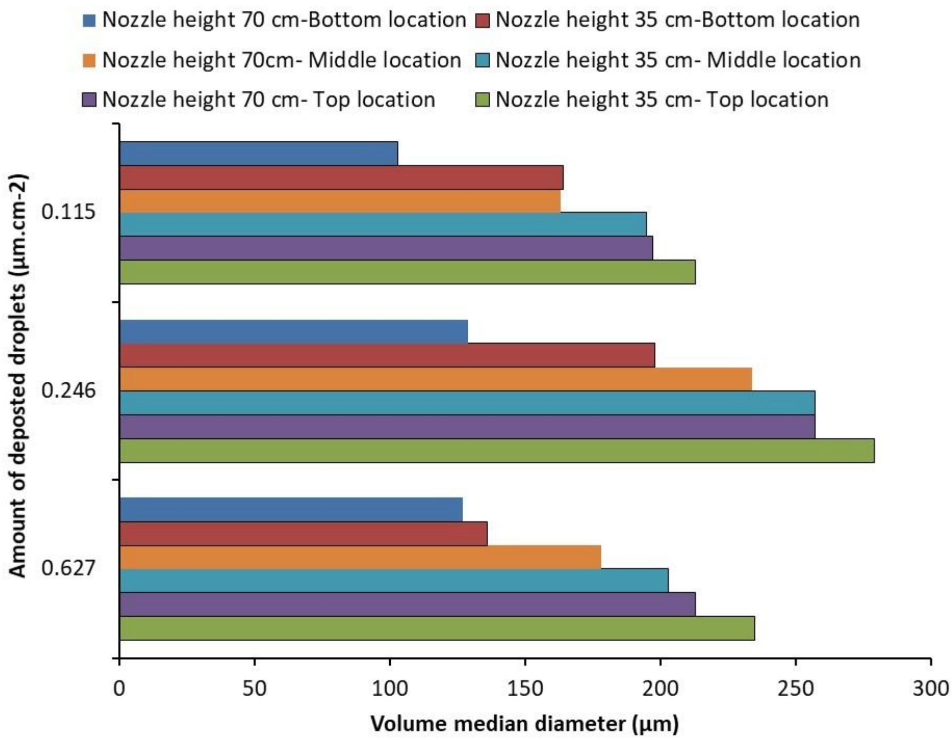

Figure 5 Correlation between droplet deposition and volume median diameter at different nozzle sizes and heights.

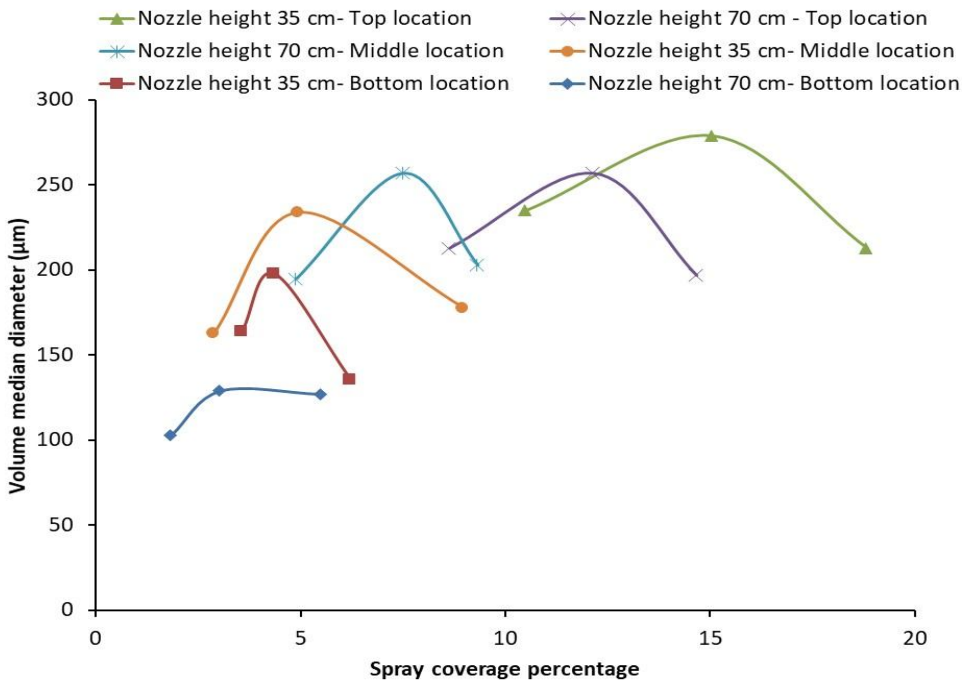

Figure 6 Correlation between spray coverage percentage and volume median diameter at different nozzle sizes and heights.

Control efficacy of the cabbage aphid

The percentage of control efficacy on the cabbage aphid was evaluated three days after spraying applications. The results indicated significant differences among the insecticide types, nozzle sizes, and nozzle heights on the aphid control. It is noteworthy; in comparison among days, the fourteenth day after spraying had significant values of control efficacy percentage, which amounted to 86.83% and 84.63% for methomyl and wide plus respectively, using the nozzle size of 02 and height 35 cm compared to the other nozzle sizes and height (Table 7).

Table 7 Percentages of the control efficacy on the cabbage aphid.

Nozzle height (cm)	Days of the assessment after spraying	Control	20% wide plus insecticide			90% Methomyl insecticide		
			Nozzle sizes					
			01	02	03	01	02	03
35	1st day	0	60.23	63.43	58.60	62.23	57.30	54.30
	7th day	0	70.43	71.00	68.60	67.57	70.67	61.20
	14th day	0	81.60	84.63	80.23	83.93	86.83	77.73
70	1st day	0	55.50	60.60	50.67	57.70	48.33	47.23
	7th day	0	59.87	69.87	59.87	61.70	71.20	61.83
	14th day	0	78.93	84.13	78.10	72.53	85.07	72.53

LSD 0.05 of the interaction among the treatments was 0.916.

Discussion

This study is valuable because it focuses on the impact of spray droplets characteristics using a knapsack sprayer to improve the control efficacy at the different layers of the cabbage plant. The main results of this present study revealed significant differences in the deposition of spray droplets, spray coverage percentage, and control efficacy percentage using different nozzle sizes and heights. The number of deposited droplets was robustly correlated to the volume median diameters depending on the used nozzle size. These results agreed with the previous studies (Alheidary, 2018; Alheidary *et al.,* 2020; Chen *et al*., 2020). The smallest values of the Dv0. 5 mean the most significant spray deposition and coverage percentage, according to Guler *et al.* (2012) and Alheidary (2019). In addition, Wolf and Daggupati (2009) studied different nozzle sizes that resulted in different droplet sizes (fine, medium, and coarse), thereby influencing both the spray deposition and coverage percentage. The study of Wolf and Daggupati (2009) and Graziano *et al*. (2017) can interpret why the values of spray deposition and coverage percentage augmented in the upper layers using nozzle size of 02 and height 35 cm at an application rate (233.01 $l.ha^{-1}$), despite this rate mediate between the rates of other used sizes (01 and 03).

Conversely, the study of Hanafi *et al*. (2016) mentioned that increasing the application rate can significantly increase the deposition and coverage percentage of the spray droplets reaching to the different layers of the plant. To justify our result, when the nozzle size 03 was used, the spray deposition and coverage percentage did not significantly increase because of using the working pressure-limited knapsack sprayer. This study did not indicate significant increases in the spray deposition and coverage percentage for the bottom layers. One of the reasons that led to this insignificant increasing was the low application rate and droplet sizes related to the nozzle size (Guo *et al*., 2019; Minov *et al*., 2016). For a fixed nozzle size, the spray deposition and coverage percentage were significantly increased when the height decreased from 70 cm to 35 cm, in agreement with (Foque and Nuyttens, 2011).

Notably, there was a robust correlation of the droplet deposition and coverage percentage with the control efficacy. Increasing the droplet deposition and coverage percentage

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significantly increased the control efficacy, mainly using methomyl insecticide at nozzle size 02 and 35 cm. Xiao *et al*. (2020) and Wang *et al*. (2019) also demonstrated these results.

Conclusions

It can be concluded from the findings of this study that the nozzle size 02 and nozzle height 35 cm compared to nozzle sizes 01 and 03 and nozzle height of 70 cm were the best for controlling the cabbage aphid through the penetrability of spray droplets into cabbage layers even the bottom layers. The outcomes also showed the superior effect of the aphid cabbage control by Methomyl sp insecticide compared to wide plus insecticide using nozzle size of 02 and height of 35cm. Therefore, it can be recommended for the farmers to use the methomyl sp insecticide to control cabbage aphids using a flat-fan nozzle of size 02 and a height of 35 cm.

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Conflicts of interest

The authors declare that they have no conflict of interest.

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بهینه‌سازی نوع نازل و نوع حشره‌کش برای کنترل شته کلم

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چکیده: در رابطه با نوع نازل و اندازه قطرات سم برای بـه حـداقل رسـاندن خطـر بـادبردگی (دریفـت) آفت‌کش‌ها مطالعات متعددی انجام شده است. اما، سمپاشی با اندازه بزرگ قطرات سم نه‌تنها تأثیری روی آفت ندارد بلکه باعث مصرف بیش از حد آن نیز می‌شود. مطالعات قبلی نشان داده است که انـدازه‌هـای کوچک قطرات سم می‌تواند با اندازه و ارتفاع مناسب نازل مرتبط باشد. این مطالعه به‌منظور تعیین اندازه و ارتفاع نازل و نوع حشره‌کش برای کنترل شته کلم انجام شده است. پارامترهای مختلفی از جمله نازل از نوع پاشش خطی یا بادبزنی (فلت فن) در اندازه‌های ۰۱، ۰۲ و ۰۳، دو ارتفاع نازل ۳۵ و ۷۰ سانتی‌متـر بالاتر از گیاه و دو نوع حشره‌کش پودر وتابل واید پلاس ۲۰٪ و پودر قابل حل متومیل برای اندازه‌گیـری نشست سم، درصد پوشش و تراکم قطرات در مکان‌های مختلف گیاه کلم بررسی شد. نتایج با استفاده از اندازه‌های مختلف نازل، ارتفاع نازل و انواع حشره‌کش‌ها اختلاف معنی‌داری در میزان قرار گرفتن سم روی گیاه و درصد پوشش سم نشان داد. بهترین میزان نشست محلول سم، درصد پوشش و میزان کنترل آفت به‌ترتیب ۰/۳۲۱ میکرون در سانتی‌متر مربع، ۱۵/۰۵ درصد و ۸۴/۸۳ درصد بود که با استفاده از اندازه نازل ۲، ارتفاع نازل ۳۵ سانتی‌متر و سم متومیل در چهاردهمین روز پس از سم‌پاشی حاصل شد. روز چهاردهم در مقایسه با روز اول و هفتم در کنترل شته کلم مؤثرتر بود.

واژگان کلیدی: نشست محلول سم، درصد پوشش، اندازه نازل، تاثیر کنترل، شته

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