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Original article

Exposure of Operators to Pesticides in Pesticide Application with Backpack Sprayer

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Abstract

Today, the importance of safe and sufficient food supply for human health is increasing day by day. In herbal production, it is tried to prevent the losses of plants due to harmful organisms. Incorrect and excessive use of pesticides in the chemical control method preferred by farmers causes negative risks in terms of human health, food safety and the environment. Studies have shown that the pesticides exposed by the applicators are higher in the backpack sprayers, which are preferred due to the differences in agricultural areas and geographical structure.

In this study, pesticide residue values that operators are exposed to in applications with backpack sprayers were investigated. For this purpose, the classical backpack sprayer has been modified by adding a boom. In the applications made with this backpack sprayer, the pesticide values that the applicator was exposed to were determined in terms of volume median diameter (μm), droplet density (droplets/cm^2) and surface coverage (%). In addition, the same evaluations were made in the target areas applied. Hollow cone nozzle N2 (8002), which is currently in use, and air induction nozzle N1 (IDK 120-02) nozzle type, which can be an alternative, were used in the experiment. The experiments were carried out in two nozzle types at two different forward (walking) speeds S1: 1 m/s and S2: 1.5 m/s) in field conditions. In the applications, the application rate was taken as 20 lt/da, the spray pressure (3 bar) and the spray height (50 cm) were taken as constant. In the applications, sampling surfaces were placed on the operator's body (head, chest, arms, legs) and on the target wedges. The volume median diameter, droplet density and surface coverage on the operator and target surfaces were investigated. Water sensitive papers were used as sampling surfaces, and the image processing program UTHSCSA (Image Tool for Windows V3) was used in the analysis of the gates. Obtained results were evaluated by statistical analysis.

On the operator's body, N2 × S2 with 52.85 μm for volume median diameter, N1 × S2 for surface coverage 0.24 % and N1 × S2 with 109 droplets/cm^2 for droplet density can be selected. On the target surface, M2 × H1 with a volume median diameter of 356.73 μm, N2 × S1 for surface coverage and N1 × S2 for droplet density can be selected. In this study, it was concluded that the modified backpack sprayer can be used by reducing the risk for the operator.

Keywords: Backpack Sprayers, Pesticide, Exposure to Pesticide, Operator, Water Sensitive Paper, Environment.

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INTRODUCTION

It is known that nearly 40% of the world's population currently faces nutritional problems, and approximately 20 million people die from hunger each year. Considering projections that the global population will reach 9.7 billion by 2050 and 10.4 billion by 2080 (Anonymous, 2022), issues related to food security and hunger are expected to escalate significantly. Meeting the growing food demand depends on increasing agricultural production. This, in turn, can be achieved either by expanding the available agricultural land or by enhancing the productivity of existing farmland.

Considering that there is no possibility of increasing agricultural areas, it is necessary to use existing areas correctly. In agricultural production, it is well known that harmful organisms, such as diseases, pests, and weeds, can cause yield losses of approximately 35%, and in the absence of any control measures, losses may reach up to 100 (Anonymous, 2008), %. Due to factors such as ease of application and rapid results, chemical control methods are commonly preferred by farmers in combating these harmful organisms. However, the use of pesticides with equipment that is not technically suitable or their unconscious overuse contributes to an increase in these negative effects.

According to the results of the studies, only a small amount of the pesticides applied reaches the target, while a significant portion is carried away to non-target areas. The degree of pesticide drift increases depending on the plant's vegetative stage during application. For instance, during full vegetation, approximately 55% of the pesticide reaches the plant, while about 20% ends up in the soil, and 25% is lost to the air, thereby drifting to unintended areas (Turgut, 2021). Droplet size plays a crucial role in determining the effectiveness and environmental impact of pesticide applications. Dengeru et al. (2022) reported that larger droplets generated by the nozzles reduce the risk of drift.

Although the tractors, which are the primary power source in agricultural activities, provide power for many pesticide application machines, they cannot be used in certain cases due to the small size of agricultural plots and the slope of the land. As in many parts of the world, in Türkiye as well, manually operated tools and machines are preferred in areas where agricultural lands are small, sloped, or uneven. Among the pesticide application tools powered by human labor, backpack sprayers constitute the most significant group. It is known that the number of backpack sprayers in Türkiye has remained high in recent years (2017-2022) (Anonymous, 2023).

Operators are exposed to varying levels of pesticides depending on the equipment and techniques used during pesticide application. Pesticides can enter the human body through inhalation, dermal contact, or ingestion. Pesticides that come into contact with operators can lead to serious health problems. Determining the amount of pesticide exposure during applications with sprayers is crucial for identifying the necessary protective measures to minimize operator exposure. This issue is particularly significant in applications using backpack sprayers, where operators are generally exposed to higher levels of pesticides. In Türkiye, backpack sprayers are commonly used for pesticide applications in crop fields and gardens, where plant production is typically carried out on small plots of land. Particularly in developing countries, the use of backpack atomizers in pesticide applications has been identified as a significant concern due to the high levels of operator exposure to pesticides (Tudi et al., 2022). Considering that pesticide drift is higher in applications using backpack sprayers (Vitali et al., 2009), it is essential to determine the amount of pesticide exposure experienced by operators.

This study aims to determine the levels of pesticide exposure on different parts of the operator's body during applications with backpack sprayers, under varying nozzle types and forward speeds.

MATERIALS and METHODS

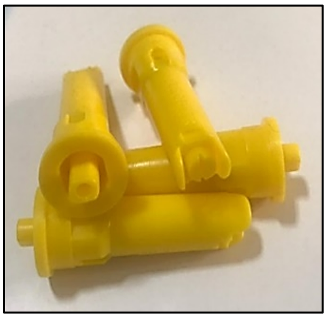
The laboratory experiments were conducted in 2023 at the Department of Agricultural Machinery and Technologies Engineering, Faculty of Agriculture, Ondokuz Mayıs University, while the field studies were carried out at the research fields of the Black Sea Agricultural Research Institute under the Ministry of Agriculture and Forestry.

In the experiments, a motorized backpack sprayer was used. Table 1 presents the technical specifications of the backpack sprayer.

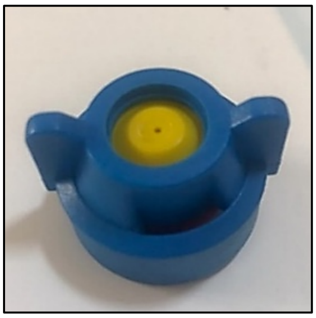
Table 1. Some technical specifications of the backpack sprayer

Items	Specifications
Engine type	4-stroke, single-cylinder
Engine power	1.1 hp /7000 rpm
Operating mode	İpli düzenek
Capacity (pesticide)	25 litres
Pressure	0-30 kgf/cm^2
Weight	9 Kg

In addition, an IDK 120-02 air induction nozzle type and a 0.2 mm plate hollow cone nozzle type with an 80^0 spray angle were used (Figure 1).



(a)



(b)

Figure 1. Air induction (a) and hollow cone (b) nozzle types used in the experiment

Water sensitive papers (WSP, 26 × 76 mm, Novartis, Syngenta Crop Protection, Basel, CH) were used for droplet analysis (Çelen, 1998; Özyurt el al, 2022). A Canon G3411 scanner was employed to capture images of the water sensitive papers for image processing. During the applications, a Prova AVM-05 anemometer was used to measure ambient air temperature and wind speed. Wooden blocks were used to secure the water-sensitive papers, while attachments were utilized to fix them onto the operator's body. Throughout the experiments, the spray application rate was kept constant at 200 L/ha, with a spray pressure of 3 bar and a nozzle height of 50 cm.

In the experiments, a motorized backpack sprayer modified by adding a boom (Duran, 2002) was used, along with two nozzle types: an IDK 120-02 air induction nozzle (Dafsari et al, 2021) and a 0.2 mm plate hollow cone nozzle with an 80° spray angle. The hollow cone nozzle was preferred because it is widely used in backpack sprayers today, while the air induction nozzle type was used as an alternative nozzle type. In a study conducted by Sehsah and Kleisinger (2009), an IDKN 120-04 air induction nozzle type was used. In pesticide applications involving backpack sprayers, the average human forward speed typically ranges between 1 m/s and 2 m/s, and a spray height of approximately 50 cm is generally preferred. Therefore, the forward speeds and spray heights selected for the experiments were based on these commonly accepted values.

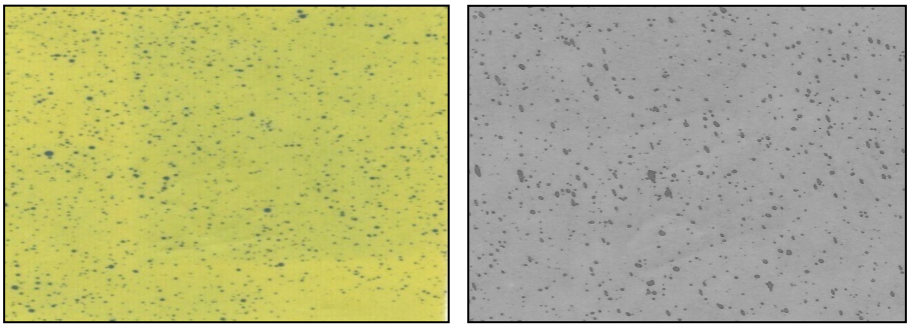
Pesticide applications were conducted using a backpack sprayer equipped with two different nozzle types (N1: IDK 120-02 air induction and N2: 8002 hollow cone nozzle) at two different walking speeds (S1: 1.0 m/s and S2: 1.5 m/s). To determine the amount of pesticide deposited on the operator during spraying, water sensitive papers were attached to specific body regions (H: Head, C: Chest, LA: Left arm, RA: Right arm, LL: Left leg, RL: Right leg) using designated attachments (Figure 2).

Figure 2. Sampling areas on the operator’s body

Additionally, to determine the amount of pesticide deposited on the target plant surface, water sensitive papers were placed on four wooden blocks positioned at 0.5 m intervals along the spray line, with two papers attached to each block (Figure 3).

Figure 3. Sampling surfaces for pesticide residues in the target area

After the spraying applications, the water sensitive papers (WSP) were allowed to dry, collected, and placed into envelopes coded according to the application parameters. The WSP were scanned at 600 dpi resolution in TIFF format using a scanner, and the images were transferred to a computer for analysis (sample surfaces were scanned in greyscale) (Figure 4).



(a) (b)

Figure 4. WSP papers after application (a) and their digital images transferred to the computer (b)

Droplet analyses on the water sensitive papers were performed using the UTHSCSA Image Tool for Windows V3 image processing software. The volume median diameter (VMD) values were calculated in Microsoft Excel using corrected droplet diameters obtained through the application of the following equation.

$$D_{v0,5} = \sqrt[3]{\frac{\Sigma(n_i.d_i)^3}{n}} \tag{1}$$

Where;

$D_{V0.5}$: Volume median diameter (µm)

n_i: Number of droplets in the diameter group

d_i: Mean value of the diameter group (µm)

n: Total number of droplets

Using the obtained volume median diameter (µm) values, droplet density (number/cm²) and surface coverage (%) were calculated. Droplet density values were determined by relating the number of droplets to the area of the WSP used in the experiments (Zhu et al., 2011; Turgut and Duran, 2025).

The statistical analysis of the experimental data was performed using the SPSS software (version 15, SPSS Inc., USA), a microcomputer program commonly employed for statistical evaluations.

RESULTS and DISCUSSION

Operator Exposure Values for Pesticides

Volume median diameter (VMD)

In pesticide applications using backpack sprayers, the volume median diameter (VMD) is preferred as an indicator for evaluating the amount of pesticide exposure experienced by operators. The results of the statistical analysis conducted on the VMD values obtained from the experiments are presented in Table 2. According to the findings, significant differences were observed in various parts of the body depending on the nozzle types and walking speeds.

Table 2. Volumetric median diameter values on the operator

Variation Sources	Spray Parameters					
	H	C	LA	RA	LL	RL
N1	74.08 b	66.25 b	59.35 b	64.12 b	127.78	124.24
N2	96.55 a	77.96 a	108.77 a	119.46 a	142.49	130.28
CV(%)	19.20	13.70	10.30	9.79	10.92	6.91
LSD	18.55	11.15	9.75	10.17	n.s	n.s
S1	95.41 a	71.08	90.39 a	92.28	126.47 b	120.42 b
S2	75.22 b	73.13	77.73 b	91.30	143.80 a	134.09 a
CV(%)	19.20	13.70	10.30	9.79	10.92	6.91
LSD	18.55	n.s	9.75	n.s	16.70	9.93
N1 × S1	87.63	70.49	65.85	65.20	126.31	119.63
N1 × S2	60.54	71.67	114.93	119.36	126.63	128.85
N2 × S1	103.20	62.01	52.85	63.03	129.25	121.21
N2 × S2	89.90	84.25	102.61	119.57	158.35	139.35
CV(%)	19.20	13.70	10.30	9.79	10.92	6.91
LSD	n.s	n.s	n.s	n.s	n.s	n.s

The difference between values with different letters is significant ($P < 0.05$)

n.s: non significant

Head region

It was determined that the VMD values at the operator's head region varied depending on the nozzle types and forward speeds. For the N1 nozzle type, the VMD values were 87.63 µm at speed S1 and 60.54 µm at speed S2, while for the N2 nozzle type, the values were 103.2 µm and 89.9 µm for S1 and S2, respectively.

Chest region

At the operator's chest region, similar VMD values of 70.49 µm and 71.67 µm were obtained at both forward speeds with the N1 nozzle type. For the N2 nozzle type, larger droplet diameters were observed at speed S2 compared to S1. This difference is thought to be due to the characteristics of the nozzle types.

Left arm region (LA)

The VMD values obtained from the operator's left arm were found to be statistically significantly affected by both nozzle types and forward speeds. For the N1 nozzle, VMD values were 65.85 µm and 114.93 µm at speeds S1 and S2, respectively, while for the N2 nozzle, they were 52.85 µm and 102.61 µm at S1 and S2, respectively. Considering that the nozzle types and speeds belong to different statistical groups, it can be stated that in both nozzle types, higher VMD values under the S2 condition may increase the operator's exposure to pesticides. The variation in VMD values on the left arm depending on nozzle type and speed is thought to be influenced by the operator's hand movements during application with the modified backpack sprayer, which included an additional boom. Hand exposure contributes to 50–75% of total exposure (Felkers et al, 2024).

Right arm region (RA)

The VMD values on the operator's right arm were significantly affected by the nozzle types. For the N2 nozzle, the VMD values were 63.03 µm at S1 and 119.57 µm at S2 forward speeds, while for the N1 nozzle, the values were 65.20 µm and 119.36 µm at S1 and S2, respectively. When examining the interaction between nozzle types and forward speeds, the S2 speed resulted in higher VMD values than S1 for both nozzle types. This situation may be attributed to the influence of the operator's walking speed during the application process.

Left leg region (LL)

When the VMD values obtained for the operator's legs were examined, it was determined that speed was statistically significant. The highest VMD value for the left leg was 158.35 µm in the S2 application for N2 nozzle types, and the lowest value was 126.31 µm in the S1 application for N1 nozzle types. Different VMD values were obtained for the legs according to nozzle types. When the droplets are close to the target surface, they merge to form larger droplets. The differences in droplet diameters on the legs are due to walking.

Right leg region (RL)

The volume median diameter (VMD) values on the operator's right leg were similar to those on the left leg. Statistically, a significant difference was found between the forward speeds. At the S2 forward speed, the VMD was 134.09 µm. The highest VMD value on the right leg was recorded as 139.35 µm in the N2 × S2 application, while the lowest VMD value of 119.63 µm was observed in the N1 × S1 application. Machado et al. (1998), stated that the highest contact with the operator's legs and feet was in the backpack sprayer with 92%.

Kuster et al. (2025) reported that chemical-resistant gloves and working coveralls offer substantial reduction in exposure, indicating that they efficiently reduce pesticide exposure and mitigate potentially associated health risks for operators, when used properly.

Surface Coverage (SC)

The results indicated that nozzle types and forward speeds had a statistically significant effect on the surface coverage (SC) in many regions of the operator's body (Table 3). However, the SC values on the right arm were not found to be statistically significant, with values of 1.14% and 1.21% for N1 and N2 nozzles, respectively. The similarity in SC on the right arm for both nozzle types may be attributed to the operator's right hand remaining steady due to the modified backpack sprayer boom. Additionally, while nozzle types significantly affected the SC on the legs, forward speeds did not show a significant effect. Overall, the highest SC were observed on the legs, likely due to their proximity to the target surface during application. The SC on the legs for N1 and N2 nozzles were determined as 6.46% and 2.88% on the left leg, and 6.68% and 3.31% on the right leg, respectively.

Table 3. Surface coverage values on the operator

Variation Sources	Spray Parameters					
	Head	Chest	LA	RA	LL	RL
N1	0.63 b	0.44 b	1.02 b	1.14	6.46 a	6.68 a
N2	0.84 a	1.13 a	1.30 a	1.21	2.88 b	3.31 b
CV (%)	15.24	19.83	22.55	12.08	12.35	11.21
LSD	0.13	0.18	0.14	n.s	0.65	0.63
S1	0.80 a	1.02 a	1.40 a	1.35 a	4.95	4.96
S2	0.67 b	0.54 b	0.93 b	0.99 b	4.39	5.03
CV (%)	15.24	19.83	22.55	12.08	12.35	11.21
LSD	0.13	0.18	0.14	0.16	n.s	n.s
N1 × S1	0.81 a	0.63	1.48 a	1.63 a	6.55	6.89
N1 × S2	0.44 b	0.24	0.56 b	0.64 d	6.37	6.46
N2 × S1	0.79 a	1.42	1.31 a	1.06 c	3.35	3.03
N2 × S2	0.89 a	0.84	1.29 a	1.35 b	2.41	3.59
CV (%)	15.24	19.83	22.55	12.08	12.35	11.21
LSD	0.18	n.s	0.20	0.23	n.s	n.s

* The difference between values with different letters is significant ($P < 0.05$)

n.s: non significant

Head region

The examination of the surface coverage (SC) on the operator's head region revealed that both nozzle types and forward speeds had a statistically significant effect on the results (Table 3). The highest SC in the head region was observed with the N2 nozzle at the S2 forward speed (0.89%), while the lowest was recorded with the N1 nozzle at the S2 speed (0.44%). The lowest SC obtained with the N1 nozzle at the S2 speed suggests that this nozzle type may allow for application at higher speeds. In contrast, the similar SC observed with the N2 nozzle at both forward speeds indicate that either speed could be suitably used with this nozzle type.

Chest region

When the surface coverage (SC) of the operator's chest region was evaluated, both nozzle types and forward speeds were found to have a statistically significant effect (Table 3). The lowest SC in the chest region was recorded with the N1 nozzle at the S2 speed, at 0.24%. Analyzing the interaction between nozzle types and forward speeds, it was observed that S2 applications resulted in lower SC for both nozzle types. The combination of N1 nozzle and S2 speed yielded the lowest overall SC in the chest region, with a value of 0.24%.

Left arm region (LA)

The analysis of the surface coverage (SC) on the operator's left arm revealed that both nozzle types and forward speeds had a statistically significant effect (Table 3). For the N1 nozzle, a notable difference was observed between the S1 and S2 speeds, with SC of 1.48% and 0.56%, respectively. This difference may be attributed to the increased drift caused by the higher walking speed. In contrast, for the N2 nozzle, the SC at S1 and S2 speeds were quite similar, measured at 1.31% and 1.29%, respectively. Therefore, both speeds may be considered suitable in terms of left arm coverage when using the N2 nozzle. However, when nozzle types and speeds are evaluated together, the lowest SC was observed with the N1 × S2 combination at 0.56%. Xuehua et al. (2020) stated that the highest concentration of pesticide residue is found on the hands and legs when using a backpack sprayer.

Right arm region (RA)

The analysis of the surface coverage (SC) rate values on the right arm showed that forward speeds caused statistically significant differences. The highest SC among the nozzle types was recorded with the N1 × S1 combination at 1.63%, while the lowest was observed with the same nozzle type at the S2 speed, with a value of 0.64%. The decrease in SC with the increased forward speed of the N1 nozzle may be attributed to enhanced drift. For the N2 nozzle, although the SC values at S1 and S2 speeds were relatively close, the S1 application resulted in a slightly lower coverage rate of 1.06%.

Left leg region (LL)

The evaluation of the surace coverage (SC) on the operator's left leg revealed that nozzle types caused statistically significant differences, whereas forward speeds did not show a significant effect (Table 3). The highest SC on the left leg was obtained with the N1 × S1 combination, at 6.55%, while the lowest SC was recorded with the N2 × S2 combination, at 2.41%. Thus, the N2 × S2 application resulted in the lowest coverage on the operator's left leg. Illyassou et al. (2019) reported that when operators use backpack sprayers, the highest pesticide exposure values occur on the chest and legs. Consequently, it has been concluded that precautionary measures must be taken for these body areas, and special attention should be given to the use of protective equipment.

Right leg region (RL)

The surface coverage (SC) values observed on the left leg were also applicable to the right leg. On the operator's right leg, the highest SC were recorded with the N1 nozzle at both forward speeds, at 6.89% and 6.46%, respectively. In contrast, the N2 nozzle resulted in lower SC at both speeds, with values of 3.03% and 3.59% (Table 3). The differences observed between the two nozzle types on both the left and right legs are thought to be due to the operator's walking speed not being entirely constant. Statistically, no significant difference was found between the forward speeds in terms of SC. The SC was 4.96% for S1 and 5.03% for S2. When nozzle types and forward speeds are considered together, the lowest SC on the operator was obtained with the N2 × S1 combination, at 3.03%.

Droplet Density (DD)

Statistical analysis of droplet density (DD) revealed that nozzle types had a significant effect on all body regions of the operator, except for the chest and right leg (Table 4). Similarly, forward speeds were found to be statistically significant for all regions except the right and left legs. Considering both nozzle types and forward speeds together, the most favorable application conditions were determined to be the N1 × S2 combination with a DD of 109.00 droplets/cm^2, and the N2 × S2 combination with a DD of 139.75 droplets/cm^2.

Table 4. Droplet density values on the operator's body

Variation Sources	Spray Parameters					
	Head	Chest	LA	RA	LL	RL
N1	148.25 b	151.38	158.25 b	153.63 b	172.88 b	191.38
N2	174.88 a	151.75	189.75 a	190.25 a	204.75 a	202.88
CV (%)	7.78	5.79	6.59	5.86	4.89	5.66
LSD	14.20	n.s	12.99	11.40	10.44	n.s
S1	171.88 a	178.75 a	194.00 a	178.50 a	189.13	200.75
S2	151.25 b	124.38 b	154.00 b	163.38 b	188.50	193.50
CV (%)	7.78	5.79	6.59	5.86	4.89	5.66
LSD	14.20	9.94	12.99	11.40	n.s	n.s
N1 × S1	168.25 a	193.75	183.00	172.00 b	179.75 b	202.25 b
N1 × S2	128.25 a	109.00	133.50	135.25 b	166.00 b	180.50 b
N2 × S1	175.50 a	163.75	205.00	185.00 ab	198.50 a	199.25 a
N2 × S2	174.25 a	139.75	174.50	195.50 a	211.00 a	206.50 a
CV (%)	7.78	5.79	6.59	5.86	4.89	5.66
LSD	20.08	n.s	n.s	16.13	14.77	17.84

The difference between values with different letters is significant (P < 0.05)

n.s: non significant

Head region

In terms of droplet density (DD) on the operator's head region, both nozzle types and forward speeds were found to be statistically significant. Considering the combinations of nozzle types and speeds, the highest DD was observed in the N2 × S1 application with 175.50 droplets/cm^2, while the lowest DD was recorded in the N1 × S2 application with 128.25 droplets/cm^2 (Table 4).

Chest region

Droplet density (DD) values on the operator's chest region were not found to be statistically significant concerning nozzle types but were significant in terms of forward speeds (Table 4). Overall, DD on the chest was not statistically significant for either nozzle type or forward speeds. However, the highest DD was observed in the N1 × S1 application with 193.75 droplets/cm^2, while the lowest DD was recorded in the N1 × S2 application with 109.00 droplets/cm^2.

Left arm region (LA)

When considering the operator's left arm, both nozzle types and forward speeds were found to have a statistically significant effect on droplet density (DD) values (Table 4). Evaluating nozzle types and forward speeds together, the DD values varied notably. The highest DD was observed in the N2 × S1 application with 205 droplets/cm^2, while the lowest DD was recorded in the N1 × S2 application with 133.50 droplets/cm^2. Comparing both nozzle types across speeds, higher forward speeds consistently resulted in lower droplet densities for both nozzle types. Konthonbut et al. (2020) reported that the use of long-sleeved shirts, trousers, and gloves reduced pesticide residue exposure in operators during pesticide applications with backpack sprayers.

Right arm region (RA)

Droplet density (DD) values obtained from the operator's right arm were found to vary significantly depending on nozzle types and forward speeds, with statistical significance confirmed (Table 4). Considering nozzle types and forward speeds together, the lowest DD was recorded in the N1 × S2 application at 135.25 droplets/cm^2, while the highest DD was observed in the N2 × S2 application at 195.50 droplets/cm^2.

Left leg region

When considering droplet density (DD) values on the operator's leg regions, nozzle types were found to be statistically significant, whereas forward speeds were not (Table 4). On the left leg, the highest DD value of 211 droplets/cm^2 was recorded in the N2 × S2 application, while the lowest DD of 166 droplets/cm^2 was observed in the N1 × S2 application. Taking both nozzle types and forward speeds into account, the lowest DD value was obtained with the N1 × S2 treatment at 166 droplets/cm^2. Similarly, Cerruto et al. (2018) reported that when using a backpack sprayer, pesticide deposition was predominantly concentrated on the lower limbs, ranging from 89% to 94%. For nozzle types, DD values at the two forward speeds belonged to the same statistical group.

Right leg region

The examination of droplet density (DD) on the operator's right leg revealed similar values to those observed on the left leg. Although DD values were not statistically significant for nozzle types and forward speeds individually, their interaction was found to be significant (Table 4). The highest DD on the right leg was recorded in the N2 × S2 application with 206.50 droplets/cm^2, while the lowest DD was observed in the N1 × S2 application at 180.50 droplets/cm^2. When considering forward speeds alone, no significant differences were found, as the results were close to each other.

The operator should be wear long clothes and prefer back-to-wind moving backward for spraying operations to minimize exposure (Wang et al, 2024).

Pesticide Values on Target Surfaces

In addition to assessing the operator's pesticide exposure, evaluations were conducted on the target surface using water sensitive papers placed on the ground. Analyses of these water sensitive papers collected during the applications were performed to determine the volume median diameter (VMD), surface coverage (SC), and droplet density (DD) values. According to the statistical analysis results, both nozzle types and forward speeds were found to be significant, as shown in Table 5.

Table 5. Evaluations on the target surface

Variation Sources	Spray Parameters		
	VMD	SC	DD
N1	278.24 b	59.95 b	214.25 a
N2	327.81 a	68.89 a	185.25 b
CV (%)	6.62	2.38	4.72
LSD	22.65	1.73	10.64
S1	343.87 a	76.54 a	149.00 b
S2	262.18 b	52.31 b	250.50 a
CV (%)	6.62	2.38	4.72
LSD	22.65	1.73	10.64
N1 × S1	331.01 a	68.97 b	171.75 b
N1 × S2	225.48 c	50.93 d	256.75 a
N2 × S1	356.73 a	84.10 a	126.25 c
N2 × S2	298.89 b	53.69 c	244.25 a
CV (%)	6.62	2.38	4.72
LSD	32.03	2.44	15.05

* The difference between values with different letters is significant ($P < 0.05$)

n.s: non significant

When examining nozzle types, the highest values for (VMD) and (SC) were obtained with the N2 nozzle type, while the highest (DD) was observed with the N1 nozzle type. Similar trends were observed for forward speeds concerning nozzle types. Specifically, the N2 × S1 application yielded the highest values for VMD (356.73 µm) and surface coverage (84.10%), whereas the N1 × S2 application produced the highest droplet density with 256.75 droplets/cm^2.

Volume median diameter (VMD)

Statistical analysis revealed that both nozzle types and forward speeds had a significant effect on the volume median diameter (VMD). The highest VMD was recorded as 356.73 µm in the N2 × S1 application, while the lowest VMD of 225.48 µm was observed in the N1 × S2 application (Table 5).

Alheidary (2019) conducted experiments using a backpack sprayer with a fixed spraying height of 50 cm, two different spray pressures (15 and 25 psi), and six nozzle types. Water sensitive papers were used to determine droplet size values during the applications. According to the research findings, the largest volume median diameter (VMD) values were obtained with the cone and fan spray nozzles, measuring 377.69 µm and 378 µm, respectively.

Considering forward speeds, for both nozzle types, higher VMD values were obtained at the lower speed (S1) compared to the higher speed (S2). Specifically, in the H2 applications, VMD values for the N1 and N2 nozzles were 225.48 µm and 298.89 µm, respectively.

When nozzle types and forward speeds are evaluated together, the highest VMD value of 356.73 µm was obtained with the N2 × S1 application, followed by 331.01 µm in the N1 × S1 application. The larger VMD values observed for the N2 nozzle provide advantages in terms of DD and SC on the target surface.

Surface Coverage (SC)

The analysis of surface coverage (SC) values indicated that both nozzle types and forward speeds were statistically significant (Table 5). The SC for the N2 nozzle type was found to be higher than that of the N1 nozzle, measured at 68.89% and 59.95%, respectively. The higher SC observed with the N2 nozzle compared to the N1 nozzle can be explained by the air-aspirated design of the N2 nozzle, which delivers larger droplets to the target surface that subsequently break up into smaller droplets upon impact, resulting in improved coverage.

Higher SC are expected at lower forward speeds; however, irregularities in the operator's forward speed may affect this outcome. When nozzle types and forward speeds are evaluated together, the highest SC of 84.10% was obtained with the N2 × S1 application, while the lowest value of 50.93% was recorded in the N1 × S2 application.

Droplet Density (DD)

In the analysis of droplet density (DD), both nozzle types and forward speeds were found to be statistically significant. Additionally, the interaction between nozzle types and forward speeds was also determined to be significant for droplet density.

The highest DD among nozzle types was obtained with the N1 nozzle at 214.25 droplets/cm^2, while the lowest DD was recorded with the N2 nozzle at 185.25 droplets/cm^2. Regarding forward speeds, DD values were 149.00 droplets/cm^2 and 250.50 droplets/cm^2 for S1 and S2, respectively. Although a higher SC is expected for the N2 nozzle due to its design characteristics, the observed results are thought to be influenced by irregularities in the operator's forward speed during the application.

When nozzle types and forward speeds are evaluated together, the highest droplet densities were obtained in the N1 × S2 and N2 × S2 applications, with values of 256.75 droplets/cm^2 and 244.25 droplets/cm^2, respectively.

In the air induction nozzle type, the expected residue values were achieved at a high rate on the operator's body and the target surface. In the air induction nozzle type, results that do not occure a risk to the operator were obtained. On the target surface, high levels of pesticide were achieved for the success of the pesticide application. It was concluded that the air induction nozzle type can meet expectations for application success in terms of both the operator's body and the target surface.

CONCLUSION

To achieve effective pesticide application, it is essential to determine the appropriate application parameters. When using backpack sprayers, both human health and environmental safety are exposed to increased risks.

To assess pesticide exposure, volume median diameter (VMD), surface coverage (SC), and droplet density (DD) values were examined. Analyses of water-sensitive papers placed on various body regions of the operator using a backpack sprayer, namely the head, chest, arms, and legs, revealed that nozzle types and travel speeds significantly influence pesticide deposition. Applications performed with air-assisted nozzles showed that VMD, SC, and DD values were lowest on the operator's legs when the forward speed was 1.5 m/s. From an operator health perspective, lower values of VMD, SC, and DD are preferred.

Incorrect selection of nozzle types and travel speeds during applications has been found to cause the greatest exposure issues on the operator's legs, arms, and head regions.

The area of greatest concern during applications was observed to be the potential disruption of parameter uniformity, particularly when the operator's forward speed is high. From this perspective, it is considered more appropriate to conduct pesticide applications over large areas using equipment other than backpack sprayers.

Knapsack sprayers being the main equipment used in both agricultural and non-agricultural settings, it is also crucial to integrate new data specific to this equipment in the model (de Graaf et al, 2024).

Additionally, it has been determined that the boom attachment added to the sprayer should be constructed from materials that do not impose an excessive burden on the operator during application.

The results showed that the air induction nozzle type produces suitable values for the VMD, SC, and DD parameters on the operator's body and the target surface. Based on these results, it has been concluded that the air induction nozzle type is preferable for pesticide applications.

In this study, it was concluded that the air-suction nozzle type used in the modified backpack sprayer could be a viable alternative to the conventionally used hollow cone nozzles in terms of operator exposure and target surface deposition values. It is considered necessary and beneficial to conduct similar studies with different nozzle types and application parameters.

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REFERENCES

Alheidary, M.H.R. (2019). Influenceof nozzle type, workıng pressure,and theır ınteractıonon dropletsqualıtyusıng knapsack sprayer. Iraqi Journal of Agricultural Sciences: 50(3):857-866.

Anonymous (2023). http://www.tuik.gov.tr/PreTablo.do?alt_id=1001 (accessed date: May 3, 2023).

Anonymous. (2008). Zirai Mücadele Teknik Talimatları. Gıda, Tarım ve Hayvancılık Bakanlığı Yayınları Cilt 4. Ankara.

Anonymous. (2022). Food and agriculture organization of the United Nations (FAO), http://www.fao.org/site (accessed date: October 10, 2022).

Çelen İ. H. (1998). Yelpaze hüzmeli püskürtme memelerinde aşınmanın pülverizasyon karakteristiklerine etkisi üzerine bir arastırma. Doktora Tezi, Tekirdağ Üniversitesi, Fen Bilimleri Enstitüsü, Edirne, Türkiye, ss: 105 s.

Cerruto, E., Manetto G., Santoro F. & Pascuzzi, S. (2018). Operator dermal exposure to pesticides in tomato and strawberry greenhouses from hand-held sprayers. Sustainability 2018, 10, 2273.

Dafsari R. A, Yu S, Choi Y, & Lee J. (2021). Effect of geometrical parameters of air-induction nozzles on droplet characteristics and behaviour. Biosystems Engin, 209: 14-29.

Dengeru, Y., Ramasamy, K., Allimuthu, S., Balakrishnan, S., Kumar, A. P. M., Kannan, B., & Karuppasami, K. M. (2022). Study on spray deposition and drift characteristics of UAV agricultural sprayer for application of insecticide in redgram crop (Cajanus cajan L. Millsp.). Agronomy, 12(12), 3196.

de Graaf, L., Bresson, M., Boulanger, M., Bureau, M., Lecluse, Y., Lebailly, P., & Baldi, I. (2024). Pesticide exposure in greenspaces: Comparing field measurement of dermal contamination with values predicted by registration models. Science of the Total Environment, 919, 170816.

Duran, H. (2002). Samsun ili'nde mısır ekim alanlarında yabancı ot ilaçlama tekniklerinin iyileştirilmesi olanakları üzerinde bir araştırma. Ondokuz Mayıs Üniversitesi. Fen Bilimleri Enstitüsü. Yüksek Lisans Tezi, 67, Samsun.

Felkers, E., Kuster, C. J., Hamacher, G., Anft, T., & Kohler, M. (2024). Pesticide exposure of operators during mixing and loading a drone: towards a stratified exposure assessment. Pest Management Science.

Illyassou, K.M., Adamou, R. & Schiffers, B. (2019). Exposure assessment of operators to pesticides in kongou, a sub-watershed of Niger. River Valley. J. Environ. Sci. Health Part B -Pestic. Food Contam. Agric. Wastes 2019, 54, 176–186.

Konthonbut, P., Kongtip, P., Nankongnab, N., Tipayamongkholgul, M., Yoosook, W. & Woskie, S. (2020). Paraquat exposure of backpack sprayers in agricultural area in Thailand. Human and Ecological Risk Assessment: An International Journal, 26(10), 2798-2811.

Kuster, C. J., Kluxen, F. M., Felkers, E., Morgan, N., Hewitt, N. J., & Durand-Reville, J. (2024). Efficiency of working coveralls and chemical resistant gloves in reducing operator exposure to pesticides. *Journal of Consumer Protection and Food Safety*, *19*(2), 155-164.

Machado N, J.G., Matuo, T. & Matuo, Y.K. (1998). Efficiency of safety measures applied to a manual knapsack sprayer for paraquat application to maize (Zea mays L.). Arch. Environ. Contam. Toxicol. 35, 698–701.

Özyurt H B, Duran H, & Çelen İ H. (2022). Determination of the application parameters of spraying drones for crop production in hazelnut orchards. J Tekirdag Agri Fac, 19(4): 819-828.

Sehsah, E.M.E. and Kleisinger, S. (2009). Study of some parameters affecting spray distribution uniformity patteren. Misr J. Ag. Eng., 26 (1), 69-93.

Tudi, M., Li, H., Li, H., Wang, L., Lyu, J., Yang, L., Tong, S., Jimmy Y. Q., Ruan, H. D., Atabila, A., Phung, D. T., Sadler, R. & Connell, D. (2022). Exposure routes and health risks associated with pesticide application. Toxics 2022, 10, 335.

Turgut E, Duran H. (2025). Determination of some spraying characteristics of different air induction nozzles. BSJ Agri, 8(2): 263-269.

Turgut E. (2021). Farklı hava emişli meme tiplerinin bazı pülverizasyon karakteristiklerinin belirlenmesi. Yüksek Lisans Tezi Ondokuz Mayıs Üniversitesi, Fen Bilimleri Enstitüsü, Tarım Makinaları ve Teknolojileri Mühendisliği Ana Bilim Dalı, Samsun, Türkiye, ss: 62.

Vitali, M., Protano, C., Del Monte, A., Ensabella, F., & Guidotti, M. (2009). Operative modalities and exposure to pesticides during open field treatments among a group of agricultural subcontractors. Archives of environmental contamination and toxicology, 57, 193-202.

Xuehua, A., Xinju, L., Jinhua, J., Lu, L., Feidi, W., Shenggan, W., & Xueping., Z. (2020). Exposure risks to pesticide applicators posed by the use ofelectric backpack sprayers and stretcher-mounted sprayersin orchards. Uman and Ecologıcal Risk Assessment: an International Journal. Vol. 26, No. 8, 2288–2301.

Wang, K., Zhang, W., Gao, H., Pan, X., Wu, X., Xu, J., & Dong, F. (2024). New Insights into Occupational Exposure and Risk Assessment of Nanopesticides and Conventional Pesticides for Agricultural Workers. *ACS Agricultural Science & Technology*, *5*(1), 128-137.

Zhu H, Salyani M, & Fox R D. (2011). A portable scanning system for evaluation of spray deposit distribution. Computers and Electronics in Agriculture, 76(1), 38-43.