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Research Article

Determination of Pesticide Exposures of Some Nozzle Types in Almond Trees Sprayed with Knapsack Sprayer

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Abstract: In this study, field trials were conducted using a knapsack sprayer to determine the pesticide exposure of the pesticide application agricultural workers (The operators) in almond tree spraying, and pesticide exposure was determined by the whole-body approach technique. An electric knapsack sprayer with a 20-liter tank capacity was used in the study. The nozzles attached to the spray boom of the knapsack sprayer can be changed in practice. Three spray nozzles were used to measure the operator pesticide exposure. These nozzles are (M1) Air induction nozzle (11002), (M2) Extended range flat fan nozzle (XR 11002), and (M3) Hollow cone nozzle (TXA8002). Each method was applied at two different spray distances (50 and 100 cm), and water-sensitive papers (WSP) were used as a sample surface in all methods. When protective clothing was analyzed, it was found that the whole body could be exposed to pesticides. According to the results, the highest coverage was obtained from standard extended range flat fan nozzle (M2) method with a 23.6 (% coverage) coverage rate and deposition of 3.956 (µL.cm^{-2}).

Sırt Pülverizatörü ile İlaçlanan Badem Ağaçlarında Bazı Meme Tiplerinin Pestisit Maruziyetlerinin Belirlenmesi

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Birikim miktarı,
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Pestisit maruziyeti,
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Öz: Bu çalışmada, badem ağacı ilaçlamasında pestisit uygulaması yapan tarım işçilerinin (operatör) pestisit maruziyetini belirlemek amacıyla bir sırt pülverizatörü kullanılarak saha denemeleri yapılmış ve pestisit maruziyeti tüm vücut yaklaşım tekniği ile belirlenmiştir. Çalışmada 20 litrelik tank kapasitesine sahip elektrikli sırt pülverizatörü kullanılmıştır. Sırt pülverizatörünün püskürtme çubuğuna takılan memeler pratik olarak değiştirilebilmektedir. Tarım işçilerinin pestisit maruziyetini ölçmek için üç püskürtme memesi kullanılmıştır. Bu memeler; (M1) Hava emişli meme (11002) (M2) Yelpaze hüzmeli meme (XR 11002) (M3) Konik hüzmeli meme (TXA8002). Her yöntem iki farklı püskürtme mesafesinde (50 ve 100 cm) uygulanmış ve tüm yöntemlerde örnek yüzey olarak suya duyarlı kartlar (WSP) kullanılmıştır. Koruyucu giysiler incelendiğinde, tüm vücudun pestisitlere maruz kalabileceğini anlaşılmıştır. Sonuçlara göre, en yüksek kaplama 23.6 (% kaplama) ve 3.956 (µL.cm^{-2}) birikim ile standart yelpaze huzmeli meme (M2) yönteminden elde edilmiştir.

1.Introduction

Pesticides are widely used in agriculture all over the world. However, a risk assessment is being conducted that estimates environmental and human health concerns based on pesticide exposure. Requirements and solutions must be found to reduce the exposure risks of operators (US. EPA, 2017;

Charistou et al., 2022). Due to advances in risk assessment techniques, potential impacts on human health and the environment are increasingly considered when deciding pesticide regulations.

Pesticides are critical in reducing crop losses, increasing yields, and improving food quality by controlling diseases, weeds, and pests (Korucu et al., 2021; Tudi et al., 2022). However, human exposure to pesticides remains a serious concern due to their inherently toxic nature (Islam et al., 2021). New application methods are being developed that provide lower pesticide exposure (Shaw et al., 2023). Due to their excellent efficiency and portability, knapsack electric sprayers have taken the lead in greenhouse management of plant diseases and insect pests. However, the precision spray nozzles of these sprayers can atomize liquids into tiny droplets, which can carry the solution away from the target.

The operators can be poisoned if they are not adequately protected from droplets that can penetrate their eyes, skin, and respiratory tract (Ren, 2019). The use of pesticide products can expose operators to skin and respiratory exposure, which can lead to health problems (Lee et al., 2024). In various situations, such as mixing, applying pesticides during agricultural operations, and harvesting crops, operators are exposed to pesticides (Kim et al., 2011; Lee et al., 2022). The two main ways to get exposed are inhalation and the skin (Nordgren &Charavaryamath, 2018). The type of agricultural activity, working hours, length of contact with pesticides, field conditions, formulation, and spraying equipment are some of the elements that affect pesticide exposure (Hughes et al., 2008; Lee et al., 2018).

Therefore, it is essential to do pesticide exposure assessments in actual field settings for operators. The operators pesticide exposure can be evaluated using various techniques, such as whole-body dosimetry (Kim et al., 2015; Samiee et al., 2023). The "Whole Body Dosimeter" for receiving and assessing pesticide deposits involves putting an The operators in a jumpsuit covering his or her entire body, acting as a worldwide collector, and then cutting the jumpsuit into many pieces after spraying. These techniques, which substitute tracers for pesticides in the trial process, are simple, economical, and easy to implement without any risk to operators (Lawson et al., 2017). These methods involve gathering samples with various articles of clothing or materials to extract pesticides before they come into touch with the skin and are absorbed. As an alternative, the skin can be cleaned with an appropriate solvent to get rid of the pesticides (Nuyttens et al., 2009; Großkopf et al., 2013). Due to the eyes, mouth, and nose on the face, pesticide exposure is particularly important (Cao et al., 2015). There are several ways to accomplish this, such as wiping, washing, and using patches (Moon et al., 2013).

The agricultural control methods used by fruit growers in Turkey to control diseases and pests have been the subject of numerous studies (Erdoğan et al., 2017). In Turkey, almonds are grown as a border tree in agricultural areas, in mixed gardens with other fruit species, or as an individual plant. Although produced in very small quantities worldwide, almonds contribute significantly to global trade in terms of value. Thanks to the state's support for certified seedlings, the number of almond production areas in Adıyaman province is increasing every year with the establishment of new orchards (Şimşek, 2015). Almond growers in Adıyaman use pesticides in chemical control as their main weapon against problematic plant protection factors. In Adıyaman, where almond cultivation is widespread, pests such as fungal diseases, insects, and weeds continue to pose a serious threat to high-quality agricultural yields. Annual fungicide and pesticide use in Adıyaman addresses the problems of recurrent anthracnose, mealy blotch, and printer bugs in almond cultivation (Erdoğan et al., 2017).

For pesticide applications, farmers make extensive use of knapsack sprayers. Standard extended range flat fan, nozzles and cone nozzles are widely used in knapsack sprayers. In this study, in addition to these commonly used nozzle types, the pesticide exposure to the human body of the air induction nozzle type was also investigated. The air induction nozzle is a new-generation nozzle type with a lower drift potential. Air induction nozzles produce larger droplets, which drift less compared to extended range flat fan and cone nozzles (Ellis et al., 2002).

The main objective of this study was to determine the pesticide exposure of agricultural operators engaged in open-field almond cultivation. For this purpose, pesticide exposures were determined at three different nozzle types and two different spray distances (50 and 100 cm) of an electric knapsack sprayer commonly used by almond growers. Water-sensitive paper (WSP) were used as sampling surfaces to determine pesticide exposures.

2. Material and Methods

2.1.Spray application techniques

An electric knapsack sprayer with a 20-litre tank capacity was used in the study. The spray nozzle of the knapsack spray can be practically disassembled and assembled. In this context, three spray nozzles were used to measure the operators pesticide exposure. These nozzles are (M1) Air induction nozzle (11002 Teejet Co.-USA), (M2) Extended range flat fan nozzle (XR 11002 Teejet Co.-USA), (M3) Hollow cone nozzle (TXA8002 Teejet Co.-USA). In addition, each method was applied at two different spraying distances, 50 cm and 100 cm. Sprayer operating conditions for the tested methods are given in Table 1 below. The spraying process of the mentioned methods was carried out taking into account the spraying period of the flesh spot disease (*Polystigma ochraceum* (Wahl.) Sacc.) on almond trees in April 2024.

Table 1. Sprayer operating conditions for the tested methods

Methods	Nozzle type	Pressure (bar)	Nozzle output ($l.min^{-1}$)
M1	Air induction	4	0.95
M2	Extended range flat fan	4	0.92
M3	Hollow cone	3	0.76

The nozzle outputs given in Table 1 were measured three times, and the liquid produced by each nozzle in one minute was determined. Before each spraying method, the sprayer tank was filled with tap water. In this study, the exposure of the operators bodies was assessed using the whole-body pesticide exposure approach.

2.2.Experimentaldesign and sample analysis

Almond trees in the trial area have a planting distance of 4x4 m. A total of 15 trees (3 blocks x 5 trees/128m^2) were used in each method, with five trees in each block (Figure 1). In all methods, the spraying application in each block was completed in 71 seconds. The amount of liquid sprayed per minute was measured to determine the application volume of each method. In the experiment, each method was applied at an average application volume of 9 $l.da^{-1}$. Each method was applied with 3 repetitions in the study.

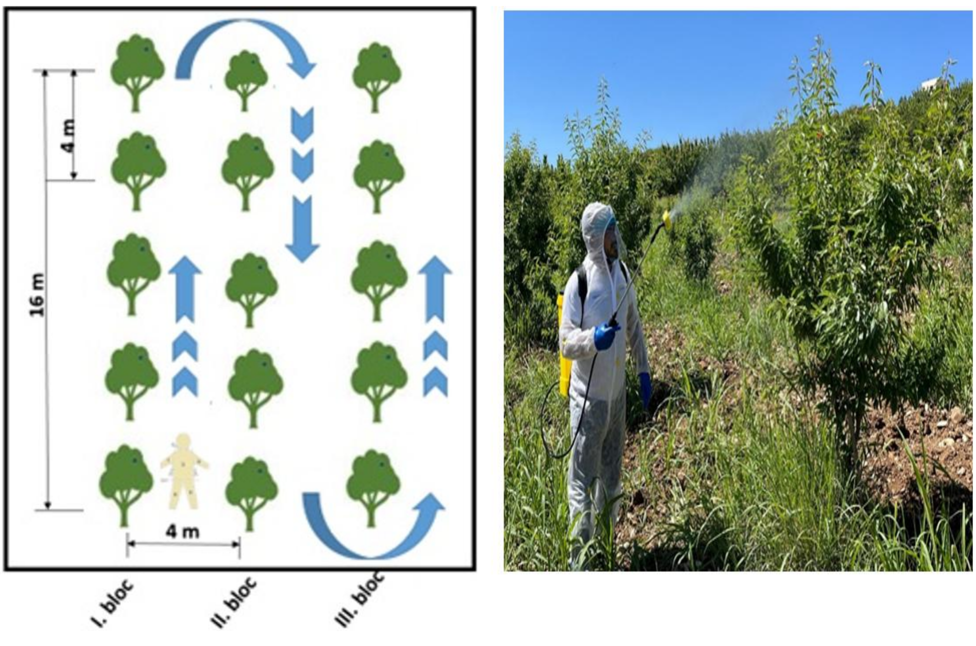

Figure 1. Schematic experimental plan and spray application.

Water-sensitive paper (Syngenta 76X26 mm) were used to determine the pesticide exposure of each method. In addition, tap water was used for the environmental health in mind. Water-sensitive paper, the operators coveralls, and their effectiveness on the whole body were observed (Machera et al., 2003). Water-sensitive cards on the coveralls were used to examine the areas that were taken. Similar to Lawson et al. (2017), 1-arm-left, 2-arm-right 3-head, 4-chest-upper, 5-chest-bottom, 6-leg-left, and 7-leg-right were used as sampling surfaces in 7 different surface of the the operators 's body (Figure 2). The WSP is attached to the operator with an adhesive material. This material allowed the WSPs to remain attached to the operator during spraying.

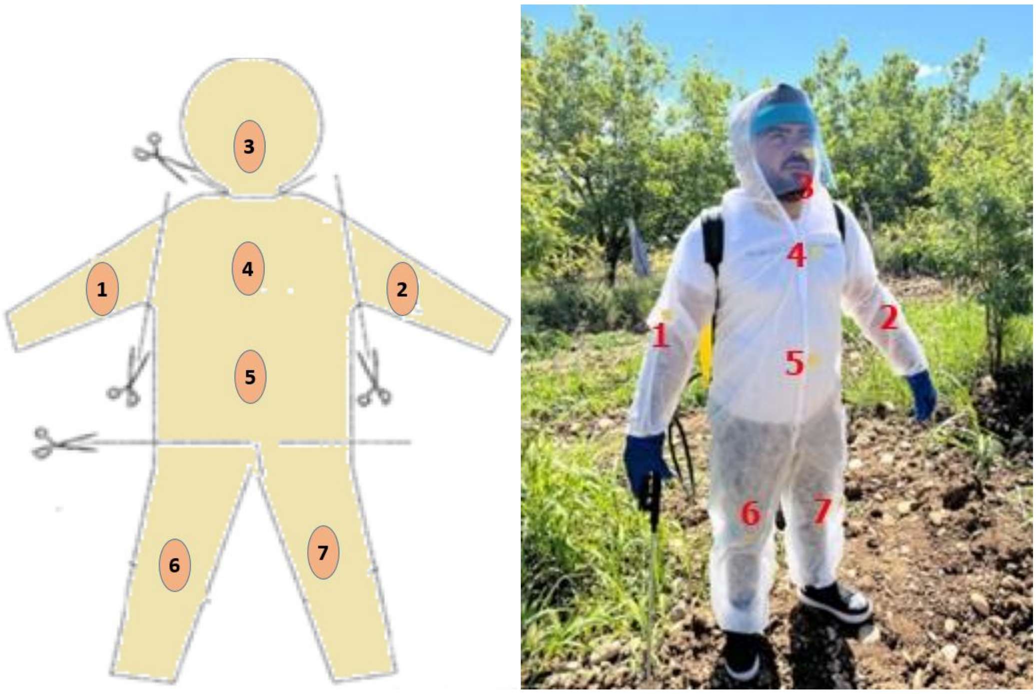

Figure 2. Water sensitive paper (WSP) sampling surfaces.

After spraying, WSPs on the operators were collected and analyzed. This was done for each method and each replicate. Meteorological conditions during spraying were measured with an anemometer (Pocket Wind IV). The mean air temperature was 27.8°C, and the mean wind speed was 1.3 m.s^{-1}.

Water-sensitive papers were used to determine the coverage rate and the amount of deposition. Firstly, droplets on water-sensitive papers were scanned at 600 dpi (600 pixels) on a scanner. The scanned cards were analyzed in the DepositScan program (Figure 3).

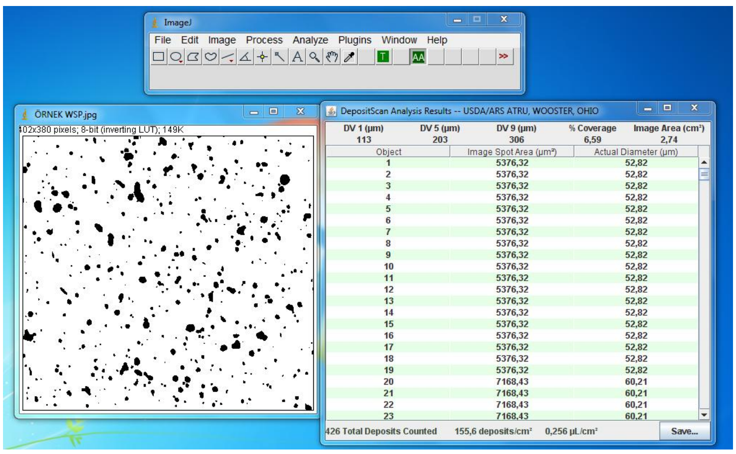

Figure 3. A Water sensitive paper analysis with DepositScan programme.

This program converts the previously scanned WSPs into an 8-bit grayscale image. Then, it selects an area to be analysed to obtain the number of points in the selected section and the area of each point. Finally, the program displays the results of the total number of points and the percentage of the area covered by the points (Zhu et al., 2011).

2.3.Statistical analysis

Statistical program JUMP 5.0 has been used to analyze coverage rates and deposition. Analysis has been done based on randomized strip block design and averages of significant factors compared via LSD tests.

3. Results

Overall coverage rates and depositions for each method are given in Table 2. Moreover, Table 2 shows the results of the average water quantities measured in the experiment with the knapsack sprayer on water-sensitive cards for two distances (50 cm and 100 cm). Accordingly, considering both distances, M2 gives the highest result regarding both Coverage rate and Accumulation amount, followed by M1 and M3 respectively (Table 2). At a distance of 50 cm, the highest coverage rate was M2 (23.6 %.cm^{-2}), and the lowest deposition was M3 (2.048 µL.cm^{-2}) and the difference between them was statistically significant ($p<0.05$). At a distance of 100 cm, the highest Coverage rate was M2 (20.2 µL.cm^{-2}), and the lowest deposition was M3 (2.698 µL.cm^{-2}), and the difference between them was statistically significant ($p<0.05$). However, the difference in accumulation amount between M3 and M1 is statistically insignificant ($p<0.05$). In addition, considering 50 cm as a distance, both coverage rate and deposition amount have a higher value than 100 cm (Table 2).

Table 2. Overall coverage rates and depositions for each method

Methods	Spray distance (50 cm)		Spray distance (100 cm)	
	Coverage Rate (%.cm^{-2})	Deposition (µL.cm^{-2})	Coverage Rate (%.cm^{-2})	Deposition (µL.cm^{-2})
M1	19.9 a	3.075 b	16.0 b	2.797 ab
M2	23.6 a	3.956 a	20.2 a	3.370 a
M3	11.6 b	2.048 c	12.0 c	2.698 b
LSD	3.27**	0.64*	1.53**	0.58*

**: the values shown with the same letters on the column are not significant in the level of $p<0.01$
*: the values shown with the same letters on the column are not significant in the level of $p<0.05$

At 50 cm spray distance, the relative body coverage distribution is given in Figure 4. At 50 cm spray distance, the coverage distribution of the body is given in Figure 4. Accordingly, M2 has more exposure to the body, followed by M1 and M3. It is also clear from Figure 4 that most exposure is to the right arm and head. This is followed by the right leg (Figure 4). It was also found that the exposure on the left leg, above the chest, and below the chest was almost the same, with M2 being the highest and M3 the lowest at all three sites (Figure 4).

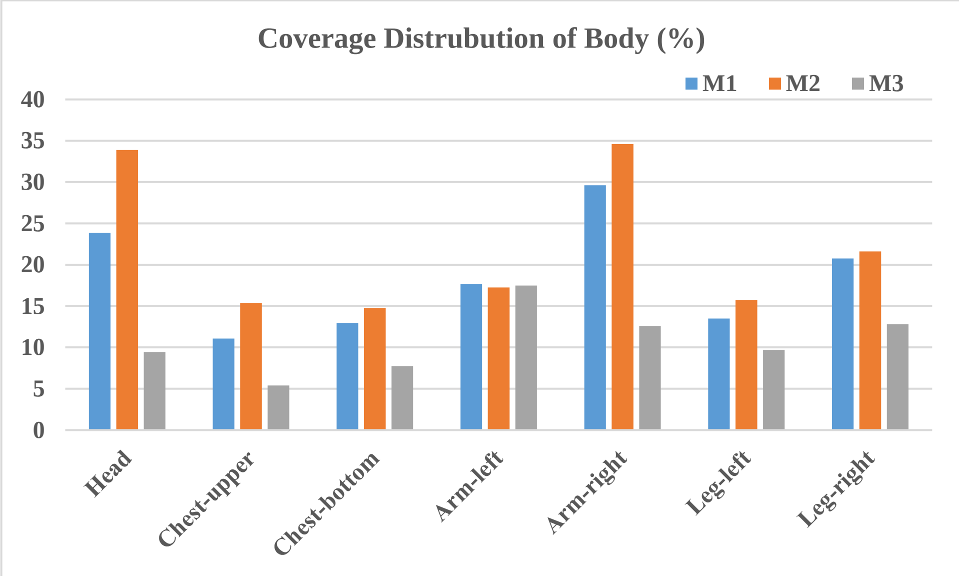

Figure 4. Relative coverage distribution of body (50 cm spray distance).

The relative deposition distribution of the body pattern at a spray distance of 50 cm is displayed in Figure 5. Accordingly, there were variations between the exposure in body regions in all methods. The most exposed body areas are the head, right leg, right arm, and left leg. The least affected areas are above and below the chest (Figure 5). The most striking observation in Figure 5 is that M1 has the highest value in the head region, and M3 has the lowest value; the opposite is observed in the right leg.In the left leg, M3 is the highest, and M2 is the lowest. In the left arm, the highest density was M3, while the densities of M1 and M2 were close to each other (Figure 5).

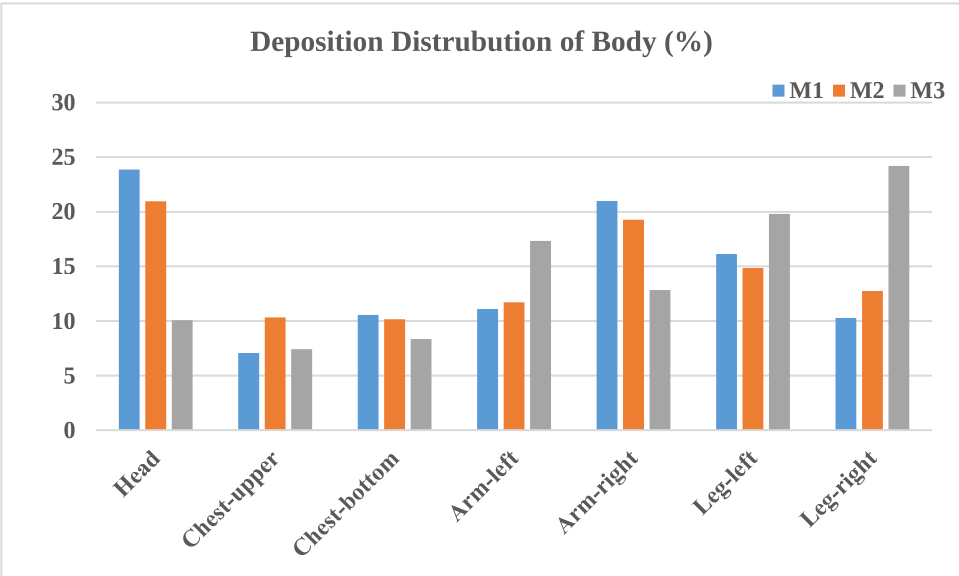

Figure 5. Relative deposition distribution of body (50 cm spray distance).

Figure 6 shows the relative coverage distribution of the body at a spray distance of 100 cm. Accordingly, M2 had the highest exposure distribution in all body parts except below the navel, followed by M1 and M3. The highest M2 value is in the head region, and the lowest M3 value is below the chest (Figure 6). In Figure 6, at a distance of 100 cm, the relative coverage distribution of the body is highest in the head and right arm. M1 and M2 values are close to each other in the upper chest, lower chest, left arm, and right leg regions.

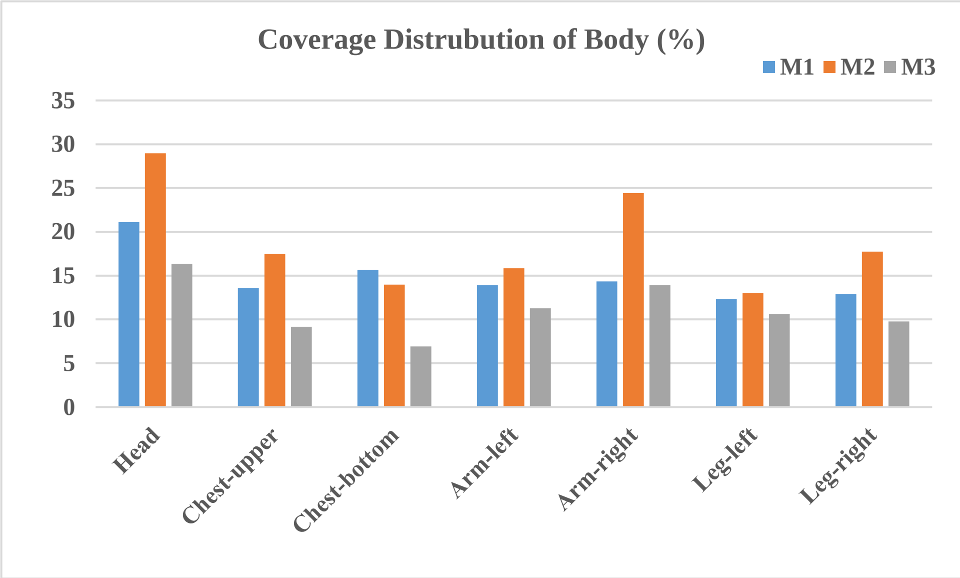

Figure 6. Relative coverage distribution of body (100 cm spray distance).

At 100 cm spray distance, the deposition distribution of the body is shown in Figure 7. Accordingly, the relative accumulation of M2 is lowest in the lower chest and left leg regions, while the opposite is the case in the other body regions and has the highest value (Figure 7). When the head and left legs are compared, M3 is highest in the left leg and lowest in the head. Another important point in Figure 7 is that M2 or M3 groups are higher in almost all body regions, while M1 is higher than the other methods only in the under-chest region. According to Figure 7, at a spray distance of 100 cm, the head, left leg, and right arm were most affected according to the relative accumulation distribution of the body.

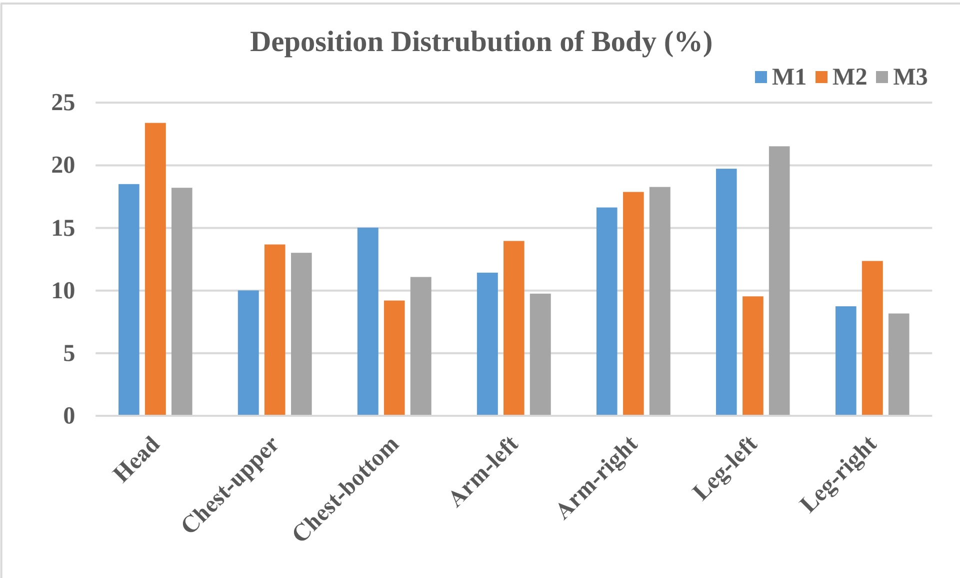

Figure 7. Relative deposition distribution of body (100 cm spray distance).

4. Discussion and Conclusion

An important component of risk assessment for crop safety and regulatory compliance is the assessment of farmers' exposure to pesticides. There are several techniques for determining pesticide exposure (Chester, 1993; Van Hemmen and Brouwer, 1995). Sampling techniques for exposure assessment in less developed countries need to be cost-effective and user-friendly (Blanco et al., 2008). In this study, when the distance between the operators and the plant is taken into consideration, it was determined that the exposure increased as the proximity to the plant increased by 50 cm. For the experiment using a knapsack sprayer, the overall coverage rates and deposits are shown in Table 1. When backpack fog blowers were used to apply fungicides in vineyards, another study monitored operators' dermal exposure. The applied range of 49.3 $mg.kg^{-1}$ a.s. to 89.2 $mg.kg^{-1}$ a.s. were the actual dermal exposure levels assessed. Transfer factors from wearing gloves and coveralls were minimal (Thouvenin et al., 2016). Patch dosimeters and hand-washing techniques were used by Baldi et al. (2006) to monitor operators exposure in vineyards using backpack sprayers. Referring to a different previous study (Machera et al., 2001), the whole body dosimetry method was used to measure the operators exposure during application with knapsack sprayer sprayers. However, according to Tsakirakis et al. (2014), the operators using knapsack sprayer sprayers and lances mounted on large tanks for vineyard spraying had potential exposure levels of the same magnitude for both hands and body. An electric hexacopter was the subject of another study examining its ability to provide reliable spray deposition and canopy penetration for use in an almond pest control program. Pesticide residues on filter papers, residues on whole unshelled almonds at three canopy heights, and spray deposition on water-sensitive papers were used to examine the effectiveness of aerial and ground techniques at varying spray volumes (Li et al., 2021).

In our study, in general, as can be seen in all figures (Figure 4, Figure 5, Figure 6, and Figure 7), the head region is the most exposed part of the body in both deposition distribution and coverage distribution, regardless of distance (50 cm and 100 cm). Residues on legs, arms, and face increase as the sprayed target tree is closer to the spraying distance. Exposure levels and the distance between the target tree and the spray boom directly affect pesticide contamination (Shaw et al., 2023). Another study by Ren et al. (2019) presented a preliminary assessment of pesticide (commercial clothianidin formulation, 20% suspension concentrate) exposure in 60 greenhouse the operators using knapsack electric sprayers in Chinese greenhouse fields. Total body unit exposure during application was 598.71 $mg.kg^{-1}$. The leg was the most exposed site, with approximately 53% of the total body exposure. However, inhalation exposure was only 0.50 $mg.kg^{-1}$. In all cases, the exposure margin was significantly greater than 100, suggesting that wearing protective equipment may reduce the hazard. In a different study, farmers' chest regions showed signs of heavy contamination, indicating that even while the legs are also exposed to a lot of pesticides during operations, pesticides may still reach the entire body (Kim et al., 2013). However, in this study on almond trees, the highest body contamination region of the operator was measured in the head (Figure 7).

Within our research, as the operators moved forward, the handle of the electric knapsack sprayer held on the right arm was closer to the spray nozzle as it was tilted towards the left leg, increasing the settling of droplets on the lower parts (legs) and exposing the legs to the pesticide. There is, therefore, a correct ratio between the right arm and the left leg (Figure 5 and Figure 7). The thighs constitute the biggest exposure region at spray heights of 80–130 and> 130 cm, according to other research with comparable findings. The legs are the body areas that are most exposed, and this may be because the operators move forward (Stamper et al., 1989; Garrod et al., 1998; Marquez et al., 2001).

Conclusion

According to the findings, the main variables affecting exposure and increases in unit exposure were application distance and nozzle types. The results of this experimental field exposure study can be used to increase the robustness of agricultural workers' exposure estimates in the context of applications using knapsack sprayer sprayers. These data can guide future studies to generate recommendations and promote new integration of plant protection strategies for large canopy plants such as the almond tree.

The operators's skill level with the tool, the integrity of personal protective equipment, the type of plant, the weather, the kind of device being used, and the kind of spray tip are just a few of the numerous variables that might impact exposure. Therefore, this study especially highlights the need for more training in personal safety management to reduce the operators exposure.

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