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Original Research

Determination of Operator Potential Risk Level from Pesticide Applications in Hazelnut Orchards

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Abstract

Hazelnuts are grown throughout the Black Sea, where the soil is not suitable for other crops, and on sharply sloping soils. Pesticides are used periodically, except for a few months of the year, against diseases and pests encountered during hazelnut production. Mechanical back sprayers and hydraulic sprayers with high pressure operated spray guns are widely used in spraying. The studies were designed to determine the risk level that may occur during pesticide applications by measuring the amount of pesticide reaching the operator and assistant in the struggle against diseases, pests, and weeds with two different sprayers (mechanical and spray gun), which are widely used for pesticide applications in hazelnut production areas in Ordu province. In the study, in order to determine the dermal exposure level, the operator and his assistant were dressed in protective overalls, and filter papers were attached to different parts of the body on the overalls. After spraying, the amount of residue on the filter papers was measured with a spectrophotometer in the laboratory, and the pesticide exposure levels of the selected target surfaces were determined. In the applications of the garden sprayer and back sprayer, 67–41% of the lower part of the body and 34–59% of the upper part of the body were contaminated for the operator, respectively. These rates were 50–46% of PDM in the lower part of the body and 50–54% in the upper part of the operator's assistant.

Keywords: contamination, emamectin benzoate, hydraulic sprayer with spray gun, lambda-cyhalothrin, operator exposure

Introduction

People meet many of their needs from plants. Depending on technological developments, agricultural production has developed and shaped over time thanks to different techniques, methods, and applications [1]. Turkey ranks first in the world in hazelnut cultivation in terms of land, production, and export. Hazelnut cultivation in the world is carried out on an area of 1015 thousand hectares [2], and approximately 739 thousand hectares of this area are located in Turkey. Hazelnut is grown especially in both the eastern and western parts of the Black Sea, where the soil is not suitable for other crops and on sharply sloping soils (more than 20 percent steep). The Central and Eastern Black Sea Region covers approximately 70% of the total

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area, with an average production area of 400 thousand hectares in hazelnut cultivation. Among the provinces in the region, Ordu has the highest hazelnut planting area with 32%, followed by Giresun with 17% and Trabzon with 9%. Turkey meets 69% of the world's hazelnut production as of 2019. Turkey is a leader in the world by realizing 61% of the world's hazelnut exports. While the hazelnut production area in Turkey is 7.3 million in 2020, the hazelnut production amount is 665 thousand tons. While Ordu ranks first in hazelnut production in Turkey with 197 thousand tons, Turkey's hazelnut export in 2020 is 157 thousand tons [3]. The incomes of approximately two to three million growers (5 percent of the country's population) depend on hazelnut cultivation. Therefore, it is easy to understand the strategic value of hazelnut production in the social and economic structure of this region [4].

Pesticides are often used to destroy weeds and insects to improve crop quality and yield. Hazelnut producers are mostly engaged in agricultural struggle against hazelnut worms, powdery mildew, weeds, and American whitefly. Due to the fact that the hazelnut growing areas are unsuitable for mechanized agriculture and excessively inclined, spraying is generally done with a single gun hanging or trailed garden sprayer and mechanical back sprayer. The spraying takes a long time, and the body parts of the operator are exposed to the pesticide due to the high plant architecture. In particular, the extent of harm from the use of pesticides, their health (chronic and acute) effects, and risks to non-target organisms and the environment [5] are not always fully known. Operators who prepare, store, transport, and apply the pesticide mix are exposed to the most body accumulation due to their job. Spraying operators and their assistants are at the highest risk for possible acute poisoning [6].

The human body is directly or indirectly exposed to pesticides. People come into direct contact with pesticides on crops, affecting the skin, eyes, mouth, and respiratory tract, causing acute reactions such as headache, irritation, vomiting, sneezing, and skin rash [7]. Some areas of the body absorb pesticides very quickly (within a few minutes) and need extra protection. Two such regions are the head and body regions. In case of pesticide spillage in this area, it is recommended to wash immediately and change clothes. It is reported that the best method is to avoid direct contact with pesticides by wearing the appropriate Personal Protective Equipment (PPE) specified on the label of the pesticide to be used [8–10]. Different trace substances, such as Tartrazine, Sunset Yellow, Brilliant Blue, and Allura Red, can be used as a representative of a pesticide to assess skin exposure [11, 12]. The analysis of such trace substances can be done risk-free and repetitively. However, in the analysis made with real pesticides, there is a risk for the analysis due to direct contact with the ingredient, and the analysis cost is quite high.

While globalization has led to the destruction of many natural green areas, the importance of plants has increased in proportion to the increasing incomes and awareness levels of people [13–16]. Increasing demand for agricultural products especially supports investments in production efficiency. Pesticides are widely used in developing countries, and their application is expected to increase in the coming years. People can be exposed to pesticides used in various ways. Skin exposure has been identified as an important route of exposure. Diseases resulting from dermal exposure (and thus absorption) can have significant impacts on human health [17]. Pesticides have significant chronic health effects in humans, including cancer, neurological effects, diabetes, respiratory diseases, fetal diseases, and genetic disorders. These health effects vary depending on the degree and type of exposure to various pesticides [18]. This increase, which causes the continuous use of pesticide mixtures in the Turkish agricultural sector, causes people, especially agricultural workers, to be exposed to pesticide mixtures in three ways: inhalation, oral intake, and dermal intake. However, the most common route of pesticide exposure for workers and neighbors (helping operators or those who act as spectators in the environment) is through the skin. People are affected by pesticides by consuming contaminated food or by exposure to pesticides during agricultural production. In the application of a pesticide, the operator's exposure to the pesticide is higher than the exposure through food consumption. Operator exposure level in pesticide application should be lower than Acceptable Operator Exposure Levels (AOELs) [19, 20]. Various diseases have been associated with contact with pesticides. Although dermal exposure assessment provides important information about the risk to spray operators, it is often an expensive and complex task.

Different reasons may be effective in the residue of the operator's body in pesticide application. These are the features of the applied product, the type of machine, the features of the nozzle, the way of application, the content of the pesticide, and ecological situations [21]. Given the great variability affected by many sources, the most accurate method to assess the dermal exposure of the plant protection products to the operator and their immediate surroundings is to use real sprayers in real operating conditions, both for the operator and for non-targets (surrounding bystanders and grazing animals) and settlements close to the point of application. It is to be measured directly on the fields (i.e. farmhouse areas; indoor pollutant levels may differ from outside air) [22]. Human health risk assessment is the process of estimating the probability of adverse health effects on humans exposed to chemical pollutants [23]. The best approach to managing the risks associated with skin exposure is to identify the hazards involved (chemicals and products), sources, and pathways of exposure, and to quantitatively assess (by measuring or modeling) exposure for further risk assessment [17]. They were chosen in this study because they were deemed useful and appropriate for estimating exposure factors with consistent results of missing evidence in estimating human trials with the methods described in the Exposure Assessment Guidelines. Dermal exposure assessment methods are described as direct and indirect methods. Previous studies to determine the effect of exposure have generally been made by choosing an appropriate method from the described methods. In this study, firstly, the exposure level was determined according to the patch sampling method by measuring directly with the trace substance instead of pesticide. Afterward, analyses were carried out by making comparative evaluations of the results obtained with the application doses of the pesticides determined by the health organizations. An estimation strategy has been developed to estimate the effect of the obtained results from the contamination value on the skin surface for potential biological references according to indirect measurement methods. The study was designed according to an easy, fast, economical, and comparable method to determine the dermal exposure of the machine types and application technique to the worker.

The nature of the product has an impact on operator exposure to pesticides, which increases when spraying pesticides on higher plants. Depending on the operating pressure and the sprayer, the resulting droplet diameter also has an effect [24].

In order to reach an acceptable standard of living, people need to have adequate nutrition. It is important to develop monitoring and control mechanisms by making scientific studies and legal regulations in order to eliminate the increasing concerns about the effects of pesticides used to protect agricultural products on human health and the environment and to increase confidence in production methods [25, 26].

In this study, according to the equipment used, pesticides are extensively used in hazelnut production with high economic value; (1) to make potential risk estimates for selected exposure points by determining the reach on the operator and his surroundings, and (2) is aimed to discuss proactive (pre-injection) exposure reduction measures that will reduce this risk.

Material and Method

Location of Application and Product Feature

The research was carried out on 1 da of land in hazelnut orchards located in the Gülyalı district of Ordu province (Fig. 1) (40°55’24’’K, 38°04’27’’D). Hazelnut plants were planted in the quarries with the old methods as 5–7 saplings and 600–800 tree ha^{-1}. Row spacing and in-row spacing are not regular. The height of the hazelnut plant is 2.5–3 m on average. Hazelnut trees are about 20 years old, and the average yield of the multisowing is 5 kgh.

Sprayers

In the chemical struggle against diseases and pests encountered in hazelnut orchards, a hand-held garden sprayer with a single nozzle spray gun and a mechanical back sprayer are generally used, which are connected to the sprayer tank pulled by a tractor. In the study, spray tests were designed according to a real insecticide application in hazelnut orchards. The operator carried out the spraying work with the garden sprayer (Kaan A.A 400 Basmacıoğlu Ltd. Şti. Burdur TR. 2 mm conical jet nozzle made of steel and brass material with hose winding reel), taking its movement from the PTO. The assistant operator assisted with the preparation of the mixture, opening the sprayer hose, and collecting and cleaning. The hand-operated mechanical back sprayer (Kaan K.16A Basmacıoğlu Ltd. Şti. Burdur TR. 1.5 mm conical jet nozzle) and the operator and his assistant carried out the preparation and cleaning works for each application, respectively. Sprayer flow rates were obtained by measuring the liter values of the liquid sprayed for 1 minute. Measurements were obtained in three repetitions for each sprayer application. Evaluations were made according to the average of the data. The operating characteristics of the sprayers used in the research are given in Table 1.

Spray Application Trials of Hazelnut Plants

Due to the mixed multisowing-like planting of the hazelnut plants in the field, the direction of progress of the operator and his assistant was carried out with a forward and curved movement through the trees along the field. Since the distances between the planting rows and the in-rows of the hazelnut plants are irregular,

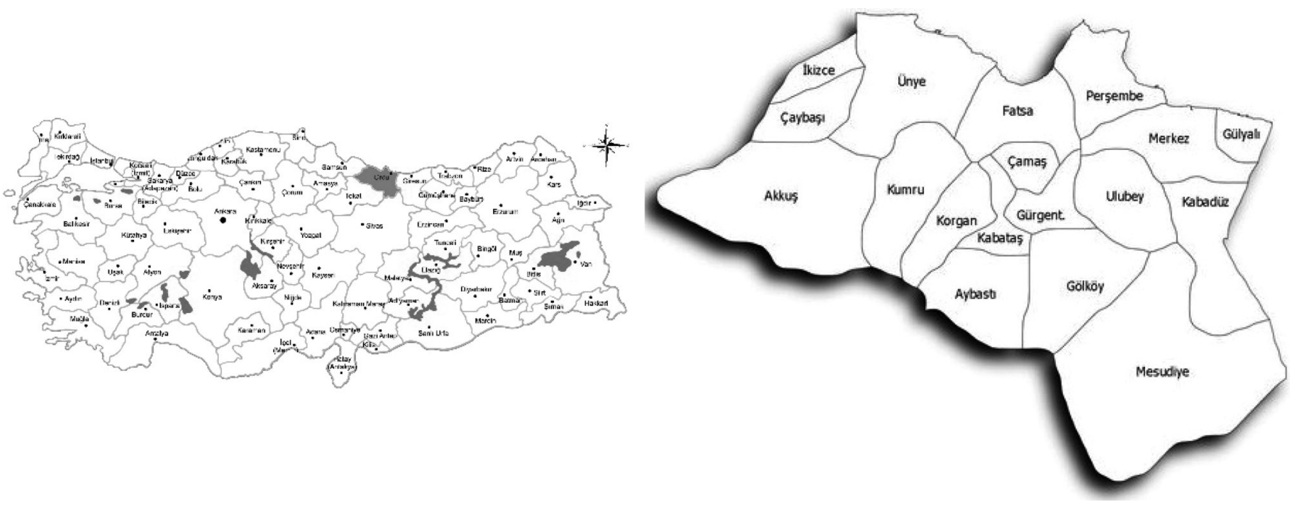

Fig. 1. The location where the trials were conducted.

Table 1. Garden sprayer and back sprayer operating characteristics.

Sprayer	Nozzle type (Conical)	Spray pressure *P* (kPa)	Nozzle flow *Q* (L min^{-1})	Speed *v* (km h^{-1})	Spray norm N_{tot} (l ha^{-1})	Trace substance C_T (g L^{-1})
Back Sprayer	1.5 mm	300	2.2	0.7x3.6	1885	10
Garden Sprayer	2 mm	300	7.2	2.1x3.6	2028	10

the results of the forward and backward walking direction applications of the operator and his assistant could not be analyzed. Trials on hazelnut plants were arranged in two phases during the growth phase BBCH 31-89. First, the operator and operator assistant dermal exposure was carried out using a garden sprayer with a PTO driven, 2 mm diameter conical nozzle, a single application head with hose, and a turbulence chamber volume adjustable spray gun, whose operating characteristics are specified in Table 1. The second trial was carried out using a manually operated mechanical back sprayer with a 1.5 mm hole diameter conical jet nozzle, the operating characteristics of which are given in Table 1. In the trial with the garden sprayer, the assistant operator did the work of preparing the mixture and carrying, straightening, and collecting the hose to make it suitable for the field conditions during the application. The operator, on the other hand, carried out the spray applications. In the application with the back sprayer, the operator and his assistant carried out the application instead of the operator in cases where the operator got tired, together with the preparation of the mixture, taking the sprayer to the back and lowering it. Until the end of the spray, the operator and his assistant carried out approximately the same work together. All applications were carried out by the same operator and his assistant. The height of the operator and his assistant is 174 cm, and their weight is 74 kg. During the trials, temperature and relative humidity were determined before each application using a thermo-hygrometer (Xiaomi Miaomiaoce MHO-C601). Wind speed was determined by anemometer (Uni-T UT363). The climate characteristics during the first trial were measured as an average temperature of 21°C, a relative humidity of 80%, and a wind speed of 8 km h^{-1}. In the second trial, 20°C temperature, 70% relative humidity, and 10 km h^{-1} wind speed were measured.

Active Substance Used for Residue Measurements

In order to determine the amount of residue formed on the operator and his assistant, a water-soluble powder form of synthetic food dye (Tartrazine) which was used as a colorant in the food industry, was used at a concentration of 10 g L^{-1}. Tartrazine has been tested for surface tack efficiency analyses instead of pesticides, and its properties are given in Table 2.

For the determination of tartrazine residue, Sánchez-Hermosilla et al. [27] linear regression equation was used. Equation (1) shows the absorbance-concentration calibration relationship (R^2=0.99). C_{wsp} is the concentration of the mixture coming to each surface (mg L^{-1}), and A is the absorbance read in the spectrophotometer.

$$C_{wsp} = 21.413A \quad (1)$$

Table 2. Color materials used in the study and their other names [9].

Feature	Tatrazine
E.E:C. Number *	E102
Color Index Number	19140
FD&C Number	FD&C Yellow 5
Acidic Dyestuff Name	Acid Yellow 23
Color Index Reference No.	Food Yellow 4
Chemical Formula	C16H9N4Na3O9S2
Molecular Weight	534.36 g/mol
CAS Number	1934-21-0
Dye Content	≥85 %

*: E.E.C. (European Economic Community) number: Color materials are included in the numerical classification between E100-E199.

Residue Measurements Data Analysis

During the application, the operator and his assistant wore polypropylene disposable overalls together with a mask and gloves. Filter papers (Eisco Labs Premium Qualitative Filter Paper) measuring body parts (right and left sides of the front and back, head, upper arms, lower arms, upper legs, lower legs, feet, chest, and back) were placed on the coverall. After the application, filter papers were collected and placed in a coded glass jar. The glass jars were stored in a cardboard box under dark conditions and transported to the laboratory to measure the amount of residue. 50 mL of distilled water (MP Minipure Dest Plus Medikal Industrial Systems Ltd. Şti. TR.) was added to the glass jar containing the filter paper element. After shaking by hand for about 30 seconds and filling into the cuvettes by waiting for about 30 minutes the absorbance was determined with a spectrophotometer (SpectroScan 60DV Biotech Engineering Management Co. Ltd. UK). The wavelength used for the spectrophotometric reading was determined as a result of the device's automatic scanning mode between 200–1200 nm, which corresponds to a maximum absorption of 427 nm for Tartrazine trace material. To make consistent comparisons between tests, the data were evaluated for 1000 L of sprayed liquid, and the results were analyzed in mg in equation (2).

The filter papers used for their actual surface corresponding to the body regions are large enough to define the total body surface, which can measure the exposure of any part of the body [28, 29]. The methodology adopted is sufficient for operator exposure assessment [30]. The patch sampling method has been preferred because it is fast, easy, and economically low-risk in terms of health [31].

$$V_{wsp} = \frac{C_{wsp}}{C_T} V_{rf} \quad (2)$$

V_{wsp} is the amount of spray liquid (mL) arriving at the filter paper element. C_{wsp} are residues on the filter paper element (mg 1000 L^{-1}), C_T is the amount of trace substance in the liquid sprayed on the field during the test, and V_{rf} is the reference volume (1000 L).

The time taken for the reference volume according to the liquid sprayed by the sprayer at a constant flow rate (Q L min^{-1}) per unit time (h) was determined according to equation (3).

$$t_{1000} = \frac{V_{rf}}{Q \cdot h \cdot 60} \quad (3)$$

t_{1000} (h), is the time taken to spray.

The amount of residue accumulated on the surface areas of the body regions was evaluated in terms of V_s administration volume (mL cm^2). When potential dermal exposure is expressed as mL 1000 L^{-1}, the results obtained in equation (4) are as in Fig. 2 and 3.

$$V_S = \frac{V_{wsp} \cdot S \cdot N_i}{N_{tot} \cdot 10^2} \quad (4)$$

Insecticide Applications

In hazelnut cultivation, chemical control is carried out against many diseases, pests, and weeds. The most common spraying is against hazelnut worms. To determine the effects of chemicals applied in the struggle against hazel worms on spraying operators, intoxication analyses were evaluated by the interpolation method, taking into account human health and ethical rules. One of the drugs recommended in the struggle against hazel worms is an insecticide with N_i 50 ml da^{-1} norm application that is recommended from Lambda-cyhalothrin, whose active substance is C_i 50 g L^{-1}.

The surface areas of the body parts were evaluated in terms of the contamination application volume (mL cm^2), and the results were examined as the amount of accumulated residue (mg cm^2).

Dermal residues were addressed to the [17–32], which used standard body surface areas for each body region rather than body surface area, as indicated in Table 3. The exposure assessment was determined according to Equation (5) for chemicals whose dose value was reported as mL da^{-1} and according to Equation 6 for drugs reported as mL da^{-1}.

$$S_{bp} = \frac{V_{wsp} \cdot S \cdot N_i \cdot C_i}{N_{tot} \cdot V_{rf} \cdot 10^2} \quad (5)$$

$$S_{bp} = V_{wsp} \cdot S \cdot N_i \cdot C_i \quad (6)$$

Dermal exposure for a given body area in Equation 4, where S_{bp} is the amount of residue deposited on the surface areas of the body regions (mg cm^2), S is the surface area of the body regions (cm^2), and C_i concentration (chemical mass mg L^{-1} per volume of fluid sprayed), was calculated based on the surface area (cm^2) of that region and the corresponding residual density (mg cm^{-2}). Thus, it is possible to estimate the amount of residue accumulated in body parts such as arms, hands, neck, and head.

Table 3. Surface areas of body parts (cm^2) [31].

Body Area	Surface area S (cm^2)	Body Area	Surface area S (cm^2)
Head	1300	Back	3550
Neck	150	Nape	110
Chest/abdomen	3550	Right lower arm	605
left lower arm	605	Right upper arm	1455
left upper arm	1455	Right hand	410
Left hand	410	Right above knee	1910
Left above knee	1910	Right below knee	1190
Left below knees	1190	Right foot	655
Left foot	655	Total	21110

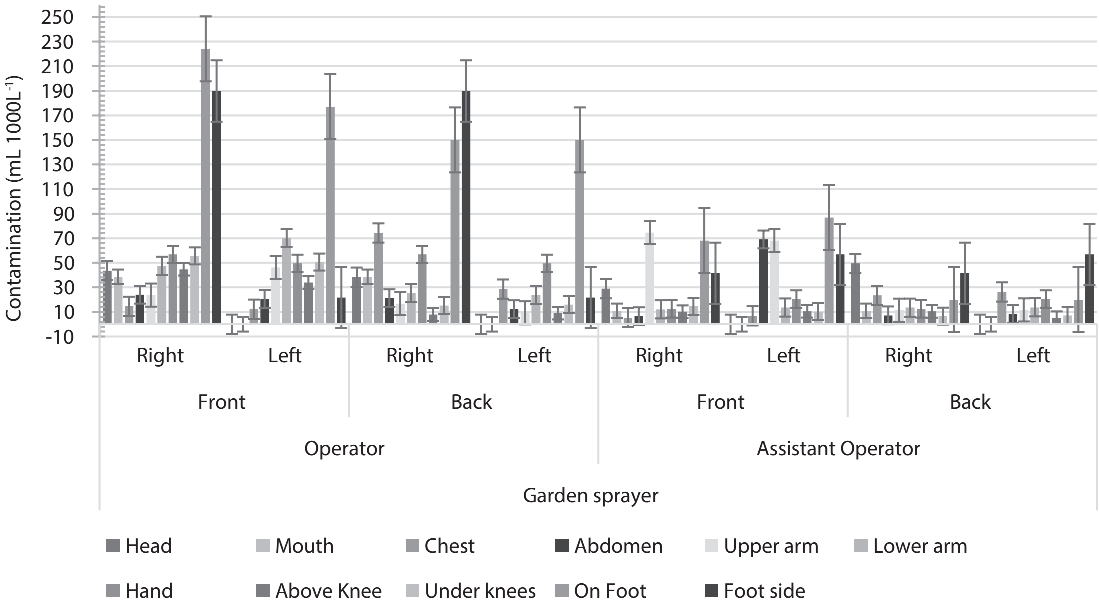

Fig. 2. Residue levels on the body parts of the operator and his assistant during spraying experiments with garden sprayers on hazelnut crops.

Statistical Analysis

Contamination on body sites was calculated relative to residues on each element (Equation 1). Comparisons between applications were made using the Minitab 13 statistical program. It was observed that the data followed a normal distribution (Kolmogorov-Smirnov test), and since the variances (Levene test) were homogeneous, significant differences at the $P<0.05$ level were obtained using the Analysis of Variance (two-way ANOVA), Tukey post-hoc test.

Results and Discussion

Spraying Application with Garden Sprayer

In a 1000 L application with a garden sprayer, 2199.90 mL (0.22%) of spray liquid was contaminated with the operator's body parts, and 1003.60 mL (0.1%) of spray liquid was contaminated with the operator's assistant (Fig. 2). The operator was exposed to contamination of 67% of the total PDM in the lower part of the body and 34% in the upper part of the body. The operator assistant was exposed to contamination of 50% of the total PDM in the lower part of the body and 50% in the upper part of the body. In the application with the Garden Sprayer, the dermal exposure values of the operator's body parts are head 4%, mouth 4%, chest 6%, abdomen 4%, upper arm 5%, lower arm 9%, hand 10%, above the knee 5%, below the knee 7%, standing 29%, and foot side 21%. Dermal exposure values of the operator's body parts were: head 8%, mouth 2%, chest 6%, abdomen 9%, upper arm 17%, lower arm 5%, hand 7%, above the knee 4%, below the knee 4%, on the feet 19%, and foot side was 19% (Fig. 2). These results were supported by Cao et al. [12], Cerruto et al. [21], Tuomanien et al. [33], and Lawson et al. [34], who gave results proportional to the method aspect of the studies they have done.

The standard deviation and coefficients of variation among the data of body regions were very small. Among the body region data, the highest standard deviation and coefficient of variation were obtained from the applications with the back sprayer. The highest standard deviation and variation values were 0.76–58% on the right side of the operator's back side, respectively. The other important standard deviation and variation coefficient change were obtained as 0.66–44%, respectively, in the right direction of the operator's front side in the application with the garden sprayer. In other applications, the standard deviation and coefficient of variation values for the body parts of the operator and his assistant were insignificant.

The contaminations caused by the sprayers in the body parts were found to be statistically significant (Table 4). The interaction of sprayers with other factors yielded an increasing number of different significant results. For each comparison, the most contamination occurred in the foot areas. The back sprayer created more contamination than the garden sprayer. While with the garden sprayer, the operator and his assistant were exposed to different amounts of residue; in the application with the back sprayer, residue levels were found at close values in both. While the amount of accumulation in the front and rear sides and right and left directions of the sprayer applications does not give meaningful results in total, three different meaningful results occur in the interaction with the operator and his assistant. The right front side of the operator was exposed to the most accumulation. In Table 4, the variance

Table 4. Variance results of contaminations in body regions.

Interaction	F-Value	df	P –Level*
Machine	112.97	1	0.000
Operator and Assistant	15.69	1	0.000
Machine x Operator and Assistant	15.20	1	0.000
Machine x Operator and Assistant x BodyAreas	3.53	10	0.000
Machine x Operator and Assistant x BodyAreas x Aspect	2.21	10	0.017

df, degree of freedom, significance level for P <0.05.

results of the amounts of dermal residues formed in different parts of the body were determined. According to these results, it was determined that the dermal exposure in mL of the sprayed 1000 L liquid on the body parts was significantly affected by the sprayer type and nozzle.

Contamination values were measured between 77.50 mL and 1124.2 mL on the operator's body parts and between 10.85 mL and 391.2 mL on the body parts of the operator's assistant in the application with the garden sprayer. These values were determined by Rincon et al. [35], who gave results in proportion to the method of their study. In this application, with a significant difference, more accumulation occurred in the lower part of the operator, especially in the feet (Fig. 2). The right foot was exposed to the highest accumulation with 753.7 mL, followed by the left foot with 370.50 mL, respectively. These values were determined by Cao et al. [12], who gave values proportional to the result that the total exposure caused the most contamination in the lower parts of the body in the imidacloprid application trials for wheat. With the garden sprayer at 300 kPa pressure, the wrong sprays made by the operator downwards, the large drops that cannot hold on to the target surfaces, and the drops suspended in the air collapse on the weed surfaces of 10–15 cm on the land surfaces with the effect of gravity. As a result of intense contact with the foot and leg surfaces of the operator moving forward, it causes proportionally more contamination to the lower parts of the body. The hands and lower arm formed the second significant contamination level with 212.70 mL and 166.95 mL, respectively, due to the fact that the hands and arms were almost perpendicular to the downward collapsing direction of the airborne drops while holding the gun for spraying. The operator's upper arm, abdomen, head, and mouth regions had the highest accumulation after the leg regions.

In the trials made with the garden sprayer, the density of the spray liquid accumulated in the body of the operator and his assistant was less than the total body accumulation as a result of the application with the back sprayer. With a garden sprayer with a nozzle diameter of 2 mm, the flow rate of the sprayed liquid is higher. In working with a high flow rate, the stay time of the operator and his assistant in the field has decreased. This has reduced the level of being affected by contamination. In order to reach the target surfaces more easily, the spray nozzle with an adjustable swirl structure created spray beams with angles smaller than 60°. Due to the large drop diameters of the sprayed liquid, it is difficult for the air to break up the large drops and change their direction during the exit from the gun. As a result, more applications can be carried forward with high kinetic energy. In this case, since the operator directs the spray jet to the tree crown region from afar, the effect of the contamination to be formed by the flow of the drops that cannot adhere to the leaf surfaces to the operator's body parts is reduced. During spraying, small drop diameter spray is also formed suspended in the air in the form of a mist cloud. The dermal exposure effect is increased as the operator passes through it and contamination of body parts as the droplets suspended in the air above collapse downward under the influence of gravity. It has been reported that the use of rechargeable or motorized sprayers instead of manually operated machines for spray application greatly reduces dermal exposure [36, 37].

Spraying Application with Garden Sprayer

In a 1000 L application with the back sprayer (Fig. 3), 2874.3 mL (0.29%) of spray liquid was applied to the operator's body parts, and 2786.3 mL (0.28%) of spray liquid was applied to the operator's assistant. The operator was exposed to contamination of 41% of the total dermal exposure in the lower part of the body and 59% in the upper part of the body. The operator's assistant was exposed to contamination of 46% of the total dermal exposure in the lower part of the body and 54% in the upper part of the body. In the application with the back sprayer, the dermal exposure values in the body parts of the operator are 5% head, mouth 6%, chest 17%, abdomen 7%, upper arm 7%, lower arm 12%, hand 12%, above the knee 8%, below the knee 6%, on foot 14%, and foot side 11%. Dermal exposure values of the operator's body parts: head 7%, mouth 3%, chest 10%, abdomen 13%, upper arm 7%, lower arm 9%, hand 10%, above knee 6%, below knee 9%, on foot 13%, and foot side 13% (Fig. 3).

In the application with the back sprayer, the operator and his assistant were exposed to similar contamination rates. Contamination values between 63 mL and 685.10 mL were measured in all body parts of the operator in the application with the back sprayer. There was accumulated between 39.50 mL and 732.70 mL in the body parts of the operator's

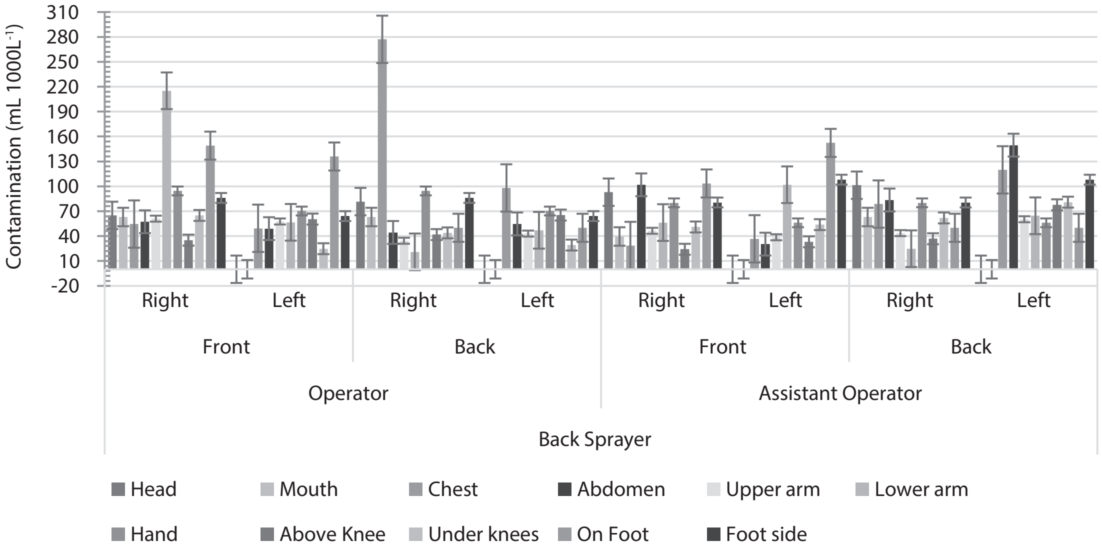

Fig. 3. Residue levels on the body parts of the operator and his assistant during spraying experiments on hazelnut crops with back sprayers.

assistant. The highest residue on body surface areas was determined on the right and left feet as 371 mL–418.30 mL, respectively, for the operator and his assistant due to friction with the vegetation. Then 329.20 mL–272.20 mL were formed in the hands due to the retention of the spray gun. Another contamination was measured on the lower arm surfaces of 339.80 mL–247.5 mL. The inevitable contamination of the lower parts of the body by the spray liquid accumulating on the grass surfaces in the field may be the explanation of the contamination in the foot areas. The exposed body parts varied according to the size of the weeds.

In the application with the 1.5 mm diameter nozzle of the back sprayer, the spraying with a large number of small diameter droplets extended the suspension time of the fine drops in the air. It can be said that long term work affects the potential dermal exposure more. In the meantime, the precipitation of airborne droplets on the operator and his assistant, who carried out the spraying, caused the body parts of both workers to be exposed to a relatively balanced contamination. In the application made with a manually operated back sprayer at an average pressure of 300 kPa, the exposure effect increased due to the fact that the pressure was not constant at the same value, the nozzle diameter was small, and the spraying angle was smaller than 60^{o}, although the spray jet was created at shorter distances.

Insecticide Spraying Applications

Lambda-Cyhalothrin Active Ingredient Insecticide Application

Lambda-Cyhalothrin is a synthetic pyrethroid insecticide used in agricultural production [38]. In the distribution of the National Toxic Information Center UZEM [39], according to the age group who applied due to agricultural chemicals poisoning in 2018, 44.71% of them are between the ages of 15–49. The distribution of the cases according to the poison group was reported as 25.40% rodenticides, 21.62% pyrethroids, and 6.26% organophosphorus. In the 2020 report of UZEM [39], it was reported that in 1954 out of 7622 people poisoned with pesticides were poisoned with insecticides-insecticides/synthetic pyrethroids. In addition, it was reported that 1873 people were poisoned with insecticides-insecticides/synthetic pyrethroids in 0–5 age group poisonings. According to PHE [40], in the UK, pesticide exposure ranked first with 37% among 681 effective substances in 2020–2021, according to product class, and pyrethroids constituted 21.73% of them. Lambda-cyhalothrin is an insecticide targeting the nervous and muscular systems. Some studies have also shown effects on the liver. This has been associated with a strong indication of an adaptive response. Lambda-chalothrin, dermal, and inhalation routes In the EFSA [41] toxicological classification, it is in the category of very toxic by inhalation, and harmful in contact with skin. In short and medium term exposure and risk assessment for operators in lambda-chalothrin administration, the dermal daily dose AOEL for a 70 kg adult – Acceptable Operator Exposure Level has been reported as 0,00063 mg kg^{-1} BW day^{-1} [41]. The amount of residue accumulated in the body after the application with an insecticide whose active ingredient is Lambda-cyhalothrin was between 0.04–0.06 mg with standard deviations (Table 5).

This value is within the specified AOEL limit. In the interviews with the producers, it was reported that they mostly did not use any pesticide protective clothing and equipment, and some spraying operators only used surgical masks with wire. Summer clothes are preferred for pesticide applications as the weather is mostly warm in the fight against hazel worms. In this case, direct skin

Table 5. Contamination of body parts for Lambda-Cyhalothrin application (μg).

Body Parts	Garden Sprayer		Back Sprayer	
	Operator	Assistant Operator	Operator	Assistant Operator
Head	1.01 ±0.11	0.49 ±0.05	1.70±0.25	1.76±0.28
Left Chest/abdomen	0.41 ±0.05	0.93±0.07	1.30±0.35	0.89±0.24
Left Back	0.50 ±0.09	0.42±0.01	2.02±0.81	3.57±1.09
left lower arm	1.16 ±0.18	0.34±0.07	1.37±0.29	2.21±0.40
left upper arm	0.68 ±0.08	0.98±0.09	1.33±0.47	1.31±0.26
Left hand	1.22 ±0.21	0.51±0.05	1.86±0.53	1.49±0.54
Left above knee	0.53 ±0.07	0.20±0.01	1.67±0.43	1.47±0.33
Left below knees	0.82 ±0.11	0.21±0.01	0.72±0.06	1.79±0.39
Left foot	4.57 ±1.28	2.72±0.36	4.16±1.08	5.55±1.77
Right Chest/abdomen	0.48 ±0.04	0.15±0.01	1.48±0.54	1.73±0.27
Right Back	1.18 ±0.50	0.38±0.01	4.26±1.13	2.15±0.57
Nape	0.95 ±0.07	0.74±0.07	1.94±0.47	2.18±0.69
Right lower arm	0.90 ±0.05	0.32±0.06	3.13±1.17	1.08±0.14
Right upper arm	0.50 ±0.05	1.06±0.63	1.27±0.23	1.19±0.20
Right hand	1.40 ±0.10	0.31±0.05	2.50±0.25	2.12±0.86
Right above knee	0.65 ±0.02	0.25±0.01	1.02±0.31	0.81±0.20
Right below knee	0.87 ±0.04	0.26±0.03	1.44±0.32	1.50±0.25
Right foot	9.29 ±2.65	2.11±0.55	4.92±1.46	4.17±1.08
Total	27.12 ±5.70	12.37±2.14	38.11±10.15	36.95±9.56

exposure occurs from the open areas of the operators, such as the head, neck, nape, arms, and hands. In addition, the surgical mask has a structure that prevents the effect of inhalation exposure very little. The pesticide concentration of the sprayed liquid is 12.33 mg L^{-1} in an application made at a dose of 50 mL da^{-1} of Lambda-cyhalothrin, whose active ingredient is 50 g L^{-1}, which is recommended for struggling hazel worms. An application of 1000 L takes 2 hours 30 minutes with a garden sprayer and 8 hours with a back sprayer. Spraying operators are under the influence of inhalation for more than half of the 4 hour period foreseen for inhalation in the application with the garden sprayer and twice the time foreseen in the application with the rear sprayer. At this time, even if they are exposed to a dose of 1% of the sprayed liquid, which is proportional to the study of OECD [42], ECHA [43], and Lambda-cyhalothrin [44], they are exposed to an inhalation of more than 0.066 mg L^{-1} inhalation level specified for Lambda-cyhalothrin. Preiss et al. [45], and Durkin [46] reported that respiratory exposure was higher if the droplets formed by spraying were fine. Accordingly, the cumulative sum of dermal and inhalation values predicts the probability of exposure of the spraying operator to contamination at concentrations approaching the acute level. Failure to use any protective clothing during application will dampen the operator's casual clothing (such as a T-shirt or linen trousers) with the spray liquid, resulting in increased dermal exposure of body surfaces.

Emamectin Benzoat Active Ingredient Insecticide Application

Emamectin benzoate is an insecticide that acts on the nervous system. This insecticide has been noted for use on a variety of pests in agricultural production. Adverse effects, possibly including degenerative changes in nervous tissue, may occur if operators do not wear protective clothing in the administration of Emamectin benzoate [46, 47]. Emamectin benzoate RfD – The acute reference dose has been reported as 0.00025 mg kg^{-1} BW day^{-1}. It is recommended to apply 218 g L^{-1} Acetamiprid + 37 g L^{-1} Emamectin benzoate at a dose of 50 mL 100 L^{-1} in the fight against hazel worms. In this application, total body contamination is 0.049 mg in the application with the garden sprayer and 0.066 mg in the application with the back sprayer (Table 6).

These residual amounts are approximately 5 times higher than Emamectin benzoate RfD. While the contamination values of the sprayer types in the total body areas produce similar results, the deposits formed on the exposed surfaces

Table 6. Contamination of body parts for Emamectin Benzoat application (µg).

Body Parts	Garden Sprayer		Back Sprayer	
	Operator	Assistant Operator	Operator	Assistant Operator
Head	1.52±0.18	0.49±0.05	2.37±0.18	2.45±0.25
Left Chest/abdomen	0.61±0.12	0.93±0.07	0.91±0.02	1.24±0.22
Left Back	0.75±0.08	0.42±0.01	2.82±0.41	4.98±1.09
left lower arm	1.74±0.35	0.34±0.07	1.92±0.26	3.08±0.84
left upper arm	1.03±0.21	0.98±0.09	1.86±0.33	1.83±0.29
Left hand	1.83±0.12	0.51±0.05	2.60±0.80	2.07±0.44
Left above knee	0.80±0.02	0.20±0.01	2.33±0.46	2.05±0.63
Left below knees	1.23±0.35	0.21±0.01	1.01±0.15	2.49±0.75
Left foot	6.85±1.43	2.72±0.06	5.81±1.91	7.74±1.87
Right Chest/abdomen	0.72±0.06	0.15±0.01	2.07±0.43	2.41±0.21
Right Back	1.76±0.18	0.38±0.01	5.95±1.97	3.00±0.94
Nape	1.42±0.51	0.74±0.07	2.71±0.36	3.04±0.92
Right lower arm	1.35±0.86	0.32±0.01	3.13±0.57	1.50±0.25
Right upper arm	0.75±0.09	1.06±0.03	4.37±1.18	1.67±0.13
Right hand	2.10±0.65	0.31±0.01	3.49±0.75	2.96±0.48
Right above knee	0.97±0.09	0.25±0.01	1.42±0.51	1.13±0.16
Right below knee	1.31±0.25	0.26±0.01	2.20±0.60	2.09±0.40
Right foot	13.94±2.97	2.11±0.05	6.86±1.43	5.16±1.58
Total	40.70±8.52	12.37±0.62	53.17±12.32	51.55±11.45

of the body give different results. Even the residues accumulated on the open surfaces of the body, such as the head, neck, arms, and hands, exceed the RfD limit of 0.015 mg in the application with the garden sprayer and 0.020 mg in the application with the back sprayer. During the spraying, the intensity of the exposure increases due to the moistening of the clothes that come into contact with the skin and inhalation. Values of pesticide application outcomes were similar to other studies [23] showing a higher health risk for adults with dermal exposure.

Conclusions

In the application of pesticides used against diseases and pests in hazelnut cultivation with different sprayer types, the levels of contamination on the body surfaces of the operators give significantly different results. In spraying, it is recommended to avoid fine spraying, which creates droplets suspended in the air for a long time, in high pressure applications with small diameter nozzles. On the other hand, it is recommended to avoid large-diameter nozzles that cause it to flow down in the air and target surfaces, to avoid coarse pulverization that creates large droplets, and to work with a medium level of pulverization. The results show that there is a significant interaction between the two sources of variation. Statistical analyses show that sprayer type and nozzle diameter significantly affect dermal exposure.

Since the spraying applied to hazelnut plants with high crown structure mostly uses upward spraying, it is likely that the applicators will be exposed to more skin exposure and inhalation rate from the spray liquid collapsing down compared to the greenhouse studies in the literature. With the droplet and vapor drift of the spray liquid active substance suspended in the air, there is a possibility of further polluting the settlements, the people and animals around them, and the environment.

It is seen that employees are less affected by the application made with the garden sprayer due to its fast application. For this reason, working with a garden sprayer should be preferred to working with a back sprayer.

The accumulation of the spray liquid made in the hazelnut orchards on the weeds in the field during the applications caused the operator and his assistant to be exposed to the highest contamination by contaminating the foot surfaces due to wandering in the field during the application.

If the movement direction and speed of the operator and his assistant are taken into account, considering the constantly changing ecological events such as wind speed, air humidity, and temperature, as well as parameters such as plant type, plant architecture, growth period, and leaf and branching structure size, more precise results can be achieved in the determination of dermal exposure. During the application, the negative effects of instantaneous climatic factors, such as application flow rate, advance speed, spray angle, land structure, and multifaceted effects on contamination, should be taken into consideration.

Based on the results from the trials, it was determined that the dermal exposure, expressed as mg per 1000 L of sprayed mixture, had a significant effect on the operator and his assistant. In the same conditions, it has been observed that previously unconsidered factors are highly effective in changing operator exposure.

The leg areas of the body are exposed to more contamination in spraying applications when the weed density is high and their height is longer. It is recommended to eliminate or reduce the amount of weeds in the field before spraying, especially in order to reduce the amount of residue that is heavily contaminated to the leg area.

The results evaluated for the hazelnut plant have the potential to give general results among the pesticides used in the cultivation of other crop plants.

After the application, children's walking around the land and neighboring gardens and grazing of poultry and other animals should be postponed until the pesticide deterioration period has passed. The results are important as they emphasize the importance of using protective clothing for the safety of spray operators.

Some of the highly toxic pesticides attack cholinesterase in the blood, which is essential for the proper functioning of the nervous system. After the application, it is recommended to have a blood test to determine that this chemical is at normal levels.

By comparing the results to be obtained with the biological monitoring method, the importance levels of the factors that are effective in determining the dermal exposure results can be determined.

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Conflict of Interest

The authors declare no conflict of interest.

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