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Farklı Tip Pülverizatörler ile Yapılan Pestisit Uygulamalarında Oluşan Operatör Maruziyetleri

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ÖZ

Bu derleme, farklı tip pülverizatörler kullanılarak yapılan pestisit uygulamalarında operatör maruziyetlerini incelemektedir. Pestisitler, tarımsal zararlılarla mücadelede kritik bir rol oynamakla birlikte, insan sağlığı ve çevre üzerinde olumsuz etkiler yaratabilir. Araştırmada, tarla pülverizatörleri, bağ ve bahçe pülverizatörleri, sırt pülverizatörleri ve insansız hava araçları (İHA) ile yapılan ilaç uygulamalarında operatör maruziyeti üzerindeki etkileri değerlendirilmiştir. Pülverizatör tasarımlarının, operatörlerin maruziyet seviyelerini etkileyen önemli bir unsur olduğu vurgulanmaktadır. Pülverizatörlerin kullanımı sırasında yaşanan zorluklar ve düzenlemelerin yetersizliği, operatörlerin sağlık risklerini artırmaktadır. Ayrıca, İHA'ların kullanımının maruziyet düzeylerini %90-99 oranında azaltabileceği gösterilmektedir. Sonuç olarak, pestisit uygulamalarının güvenliğini artırmak için kişisel koruyucu ekipman kullanımı, eğitim ve ekipman tasarımının önemi vurgulanmakta; sürdürülebilir tarım uygulamalarının geliştirilmesi gerektiği belirtilmektedir. Bu çalışma, tarımsal güvenlik ve operatör sağlığı açısından önemli bulgular sunmakta ve gelecekteki araştırmalara ışık tutmaktadır.

Operator Exposures in Pesticide Applications Using Different Types of Sprayers

Review Article

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ABSTRACT

This review investigates operator exposure to pesticides during applications using various types of sprayers. Pesticides play a crucial role in managing agricultural pests; however, they can pose significant risks to human health and the environment. The research evaluates the effects of field sprayers, vineyard and orchard sprayers, backpack sprayers, and unmanned aerial vehicles (UAVs) on operator exposure levels. The study emphasizes that the design of sprayers is a critical factor influencing operator exposure. Challenges encountered during the use of sprayers, along with inadequate regulations, contribute to increased health risks for operators. Furthermore, the findings indicate that the use of UAVs can reduce exposure levels by approximately 90-99%. In conclusion, the study underscores the importance of implementing personal protective equipment (PPE), providing training, and improving equipment design to enhance the safety of pesticide applications. It also highlights the need for the development of sustainable agricultural practices. This research offers significant insights into agricultural safety and operator health, paving the way for future investigations in this field.

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Introduction

Pesticides are essential for managing harmful or destructive pest species in crops, such as weeds, insects, and disease-causing organisms (Karunamoorthi et al., 2012). Pesticide application is currently a crucial control management tactic to guarantee food supply and distribution globally (Oliveira Pasiani et al., 2012). However, reports indicate that some pesticides are extremely hazardous to the environment and human health (Soko, 2018). According to various studies, the rate of poisoning, disability, and mortality due to pesticide exposure may increase with the inappropriate use of pesticides (Kangavari et al., 2024). Pesticide poisoning is the leading cause of death and harmful health effects globally. However, the true prevalence of pesticide poisoning among farmers in less developed countries is difficult to determine. Thus, farmers now face greater health hazards as a result of pesticide use (Houbraken et al., 2016; Kangavari et al., 2024).

Protective measures that can reduce the severity of the effects of pesticides on farmers' health include avoiding associated health risks, adopting protective behaviors, using personal protective equipment, and using pesticides appropriately during handling, transport, mixing, and spraying (Fan et al., 2015). Most farmers do not consider using safety measures that can reduce the likelihood of pesticide poisoning. Therefore, it is very important to identify the features that farmers find successful when it comes to preventive measures for pesticide use (Sharifzadeh et al., 2019). Analysis of previous safety research reveals that several variables can influence farmers' preventive practices in case of pesticide poisoning (Rezaei et al., 2019). When farmers use pesticides, they implement preventive measures based on several factors such as age, education level, farming experience (Isin and Yildirim, 2007). Perceived risk, awareness, attitudinal and belief variables, perceived barriers, facilitators, health expectations, social norms, emotions, physiological arousal and intention (Afshari et al., 2019).

The terms 'toxicity' and 'risk' have different meanings regarding pesticide safety. The term 'toxicity' describes the innate capacity of a substance to be poisonous (Garud et al., 2024). The risk (hazard) of a particular pesticide is determined by the toxicity of the substance in question and the type and amount of exposure. Risk (hazard) should be determined from information on exposure and toxicity. In general, highly toxic pesticides have a higher potential for adverse human effects than less toxic ones (Daraban et al., 2023). However, other factors that significantly affect the risk of poisoning include the concentration of pesticides in the formulation, the duration of exposure, the point of entry of the pesticide into the human body, and the technical features of the sprayers types (Tudi et al., 2022). The design of sprayers poses significant challenges that hinder users' ability to perform their tasks efficiently. A notable example is the difficulty associated with opening the tank cap, which can result in users being exposed to hazardous chemicals. Furthermore, operators are often in direct contact with the sprayer during the spraying process, leading to both direct and indirect exposure to pesticides. Such exposure can result in various health issues. Additionally, the regulations governing the design of sprayers frequently overlook the actual working conditions faced by users. Albert et al (2025) in the study indicates that a four-level analysis of pesticide exposure situations. The first level examines the challenges faced by farmers during sprayer use and how these challenges increase exposure risks. The second level emphasizes that the design of sprayers often overlooks the real needs of farmers, thereby heightening health risks. The third level indicates that legal regulations typically only meet minimum requirements, complicating the work of designers. The fourth level highlights that the interests of farmers are not adequately represented in regulatory processes, leading to neglect of health and safety issues. Overall, these four levels underscore the complexity of pesticide exposure issues and the necessity for a multi-level approach to address them.

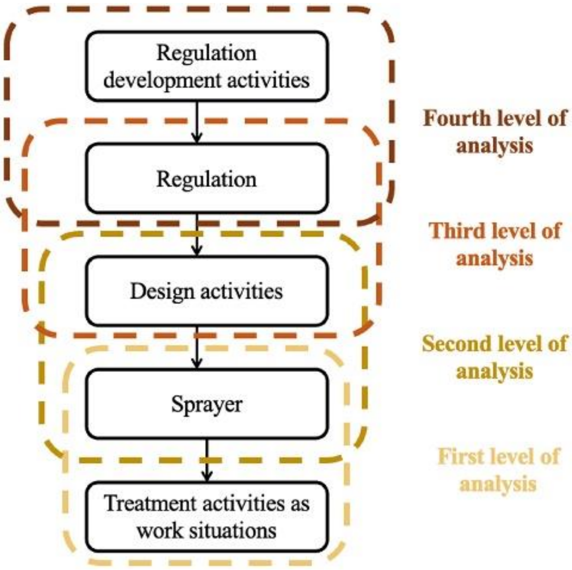


Figure 1. Processes affecting levels pesticide exposure (Albert et al., 2025)

The aim of this study is to comprehensively investigate operator exposure to pesticides during applications utilizing various types of sprayers, while also evaluating the associated health impacts of such exposure. Furthermore, this research endeavors to develop and recommend safe application methodologies and robust protective measures designed to mitigate pesticide use and enhance operator safety in agricultural practices.

Materials and Methods

This review study utilized databases such as Web of Science, ScienceDirect, Google Scholar, and ResearchGate to gather publications up to December 20, 2025. The keywords used for the search were pesticide exposure, operator safety, spraying application techniques, personal protective equipment (PPE). The topics examined in the review utilize a narrative-based approach.

Effects of Pesticide Exposure on Operators During Pesticide Application Using Field Sprayers

Pest management is an essential aspect of modern agriculture, yet it poses significant risks to operators during pesticide application, particularly when using field sprayers. Several factors contribute to the extent of pesticide exposure among agricultural workers, including the properties of the pesticide compounds, agronomic factors such as crop height and application techniques, and environmental conditions like wind speed and direction (Boonupara et al., 2023; Fattahi et al., 2025).

Operators often face challenges in accurately estimating their exposure levels during routine activities, as direct measurement is complicated by various factors, including climatic conditions and the diversity of application methods (Colosio et al., 2012). Consequently, exposure levels are frequently predicted using models designed for this purpose. Notable models include the Bystanders, Residents, Operators, and Workers Exposure models (BROWSE), the German Operator Exposure Model, the UK Predicted Operator Exposure Model (UK POEM), and the European Predicted Operator Exposure Model (EUROPOEM) (Lammoglia et al., 2017; Wong et al., 2018).

A study conducted by Lebailly et al. (2009) utilized a whole-body approach, where operators wore coveralls and cotton gloves during a one-day application of the herbicide is oproturon on winter wheat and barley. This study measured contamination across twelve body parts, revealing that hands and forearms were the most contaminated, with a staggering 64% of exposure occurring during the mixing and loading phases. This indicates that the type of spraying equipment used significantly impacts exposure levels, with rear-mounted sprayers associated with higher contamination rates. Notably, two-thirds of the total daily exposure occurred during the mixing-loading process, underscoring it as the most hazardous activity in outdoor pesticide application. Furthermore, the study highlighted that conventional pesticide-related criteria, such as field area and application time, did not correlate positively with exposure levels. In the study by Ramwell et al. (2004), it was stated that the outer surface of the field sprayer was also exposed to pesticides during application, which increased the operator's exposure. Residue measurements were conducted on the field sprayer and the attached tractor (Table 1). The delivery system recorded the highest number of pesticide detections, and for all sprayers, pesticides were found on both the boom and the nozzle. For this reason, most producers reduce the spray height and pressure during spraying to minimise drift (Seyfioğlu et al., 2023). Overall, the number of detections on the mudguards was at least double that of the rest of the tractor's body, including the door, rear window, and windscreen.

Table 1. Pesticide expose in tractor and field sprayer sample points

Sample	Number of positive detections of all pesticides per sprayer (n = 26)	Number of zero detections per sprayer	Mean pesticide dose (mg m−2)
Boom	42	0	41
Nozzle Spray tank	236	0	149
Spray tank	169	0	7.2
Mudguard (n = 25)	119	3	7.2
Door	61	4	0.5
Rear window (n = 24)	50	7	0.6
Windscreen	31	11	0.3

This finding suggests that relying solely on these criteria may not adequately account for the complexities of operator exposure during pesticide application (Lebailly et al., 2009).

In conclusion, understanding the multifaceted factors influencing pesticide exposure is crucial for developing effective risk mitigation strategies. Continuous research and targeted training for operators can enhance safety measures and reduce the health risks associated with pesticide application in agricultural settings.

Effects of Pesticide Exposure on Operators During Pesticide Application Using Vineyards and Orchards Sprayers

The use of pesticides in vineyards and orchards is a common agricultural practice aimed at protecting crops from pests, diseases, and weeds. However, these applications pose significant health and environmental risks due to the physical characteristics of the areas, application methods, and frequency of use. Factors such as protective measures, climatic conditions, and user awareness also substantially influence pesticide exposure levels (Bureau et al., 2022). In vineyards and orchards, the vertical arrangement of trees and the need to penetrate the foliage often necessitate the use of equipment like air-assisted sprayers (Figure 2).

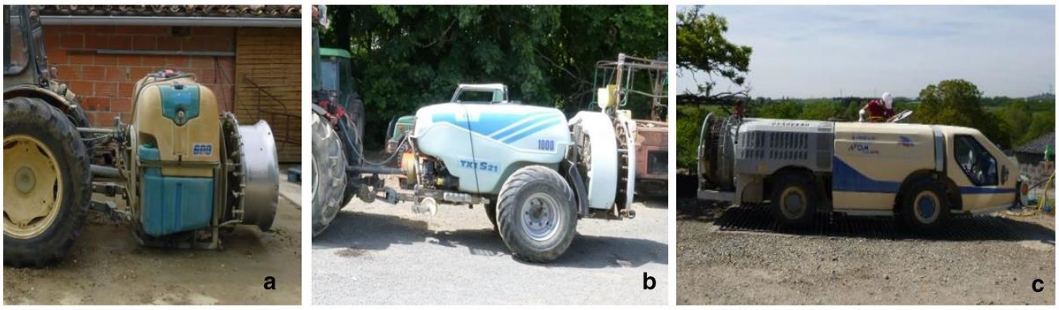


Figure 2. Types of sprayers commonly used in vineyard and orchard agriculture: (a) Rear-mounted sprayer. (b) Trailed sprayer. (c) Self-propelled sprayer (Bureau et al., 2022)

This increases the potential for pesticide drift. research indicates that up to 30% of applied pesticides may drift to non-target areas, contaminating water sources and residential zones (Dubuis et al., 2023). Workers are exposed to pesticides primarily through inhalation and dermal contact during mixing, loading, and spraying operations (Tsakirakis et al., 2014). A study by Lebailly et al. (2009) found significant pesticide residues on workers' hands, arms, and torsos, often due to inadequate use of personal protective equipment (PPE). Chronic pesticide exposure in vineyards has been linked to respiratory illnesses, neurological disorders, and cancer (González-Alzaga et al., 2014; Ahrens et al., 2024). Additionally, pesticide accumulation in soil, leaching into groundwater, and adverse effects on non-target species, especially pollinators, represent critical environmental concerns (Wang et al., 2020). The adoption of drift-reducing technologies and the establishment of buffer zones are essential for mitigating these risks. In orchards, pesticide use is often carried out by non-professionals and is frequently unregulated. A lack of training and improper use leads to over-application and unintended exposures (Morgan, 2012). Gardeners often lack access to PPE and fail to comply with safety guidelines. Residues from pesticides used in orchards can also spread through air and water, affecting surrounding areas (Afandi and Irfan, 2024). In urban ecosystems, pesticide exposure has been associated with significant declines in insect populations. Sánchez-Bayo and Wyckhuys (2019) highlighted the role of pesticide use in gardens in contributing to these declines, emphasizing the need for more environmentally friendly alternatives.

Key factors influencing pesticide exposure in vineyards and orchards include application techniques, PPE use, climatic conditions, and user awareness. For instance, applications conducted at low wind speeds and moderate temperatures reduce drift and operator exposure (Nuyttens et al., 2011). Educational programs and community-based awareness campaigns can promote safe use practices, thereby reducing risks (Fan et al., 2015). Various measures are recommended to reduce pesticide exposure and associated risks. The adoption of precision agriculture technologies can optimize pesticide use and minimize drift. Integrated Pest Management (IPM) strategies, which combine biological controls with pesticide use, offer a sustainable alternative (Kogan, 1998). Furthermore, regulatory measures for pesticide use, particularly in residential and urban areas, should be strengthened (Rezaei et al., 2019).

Addressing the health and environmental impacts of pesticide use in vineyards and orchards requires a multifaceted approach. Enhancing protective measures, adopting safer application techniques, and promoting sustainable pest management practices are crucial for safeguarding human health and protecting the environment. Future research should focus on developing innovative solutions and policies to further reduce these risks and ensure the sustainability of agricultural and gardening practices.

Effects of Pesticide Exposure on Operators During Pesticide Application Using Backpack Sprayers

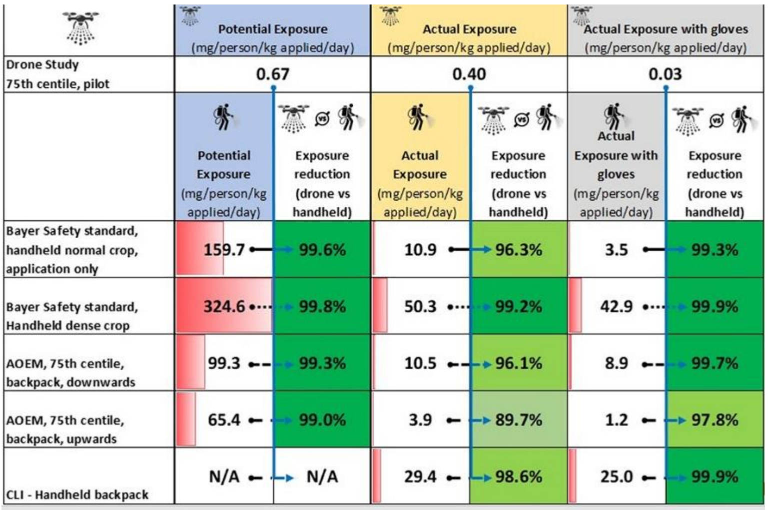
Backpack sprayers are widely utilized in agricultural settings, particularly in developing countries, due to their convenience and effectiveness in applying pesticides. However, the health risks associated with pesticide exposure during the application process are significant and warrant thorough investigation. Studies have demonstrated that operators using backpack sprayers are at risk of both dermal and inhalation exposure to harmful chemicals (Liu et al., 2019). Research conducted in various regions has highlighted the correlation between the type of sprayer used and the level of exposure experienced by operators. For instance, a study in Egypt found that pesticide applicators using knapsack sprayers exhibited higher levels of contamination on their bodies compared to those using conventional motor sprayers (Elhalwagy et al., 2010). This finding underscores the need for improved safety measures and protective equipment for operators who regularly handle these devices.

Moreover, a recent analysis of glyphosate exposure among backpack sprayer users in Thailand revealed that urinary biomarkers indicated low levels of health risk; however, the study emphasized the importance of PPE to mitigate exposure (Chaiklieng et al., 2024). The findings suggest that while the immediate health risks may appear manageable, continuous exposure without adequate protection could lead to long-term health issues. In France, a study assessing herbicide exposure among gardeners and municipal workers using backpack sprayers found that dermal exposure was the predominant route of pesticide entry into the body (Boulanger et al., 2023). The research indicated that the levels of contamination approached those observed in agricultural workers, raising concerns about the occupational safety of non-agricultural users of these sprayers.

In conclusion, while backpack sprayers are an essential tool in modern agriculture, the associated risks of pesticide exposure to operators cannot be overlooked. Enhanced training on the use of PPE, along with ongoing monitoring of exposure levels, is crucial to safeguard the health of those involved in pesticide application.

Effects of Pesticide Exposure on Operators During Pesticide Application Using Unmanned Aerial Vehicles (UAVs)

In recent years, the use of UAVs in agricultural applications has been on the rise. UAVs are noted for their efficiency and flexibility in pesticide application. However, the health effects of this new technology, particularly concerning pesticide exposure among operators, pose significant concerns. Research has been conducted to examine the levels of operator exposure during UAV-based pesticide applications and to compare these levels with those associated with conventional application methods (Yan et al., 2023). One study evaluated operator exposure during the mixing and loading phases of UAV-based pesticide application. The findings revealed that mixing concentrated products resulted in the highest levels of exposure, whereas transferring diluted mixtures to the UAV tank led to significantly lower exposure figures (Felkers et al., 2024). Additionally, the use of PPE was shown to substantially mitigate potential exposure during these phases. Another study indicated that operator exposure levels during UAV applications were reduced by 90-99% compared to traditional handheld sprayers (Figure 3).



	Potential Exposure (mg/person/kg applied/day)		Actual Exposure (mg/person/kg applied/day)		Actual Exposure with gloves (mg/person/kg applied/day)	
Drone Study 75th centile, pilot	0.67		0.40		0.03	
	Potential Exposure (mg/person/kg applied/day)	Exposure reduction (drone vs handheld)	Actual Exposure (mg/person/kg applied/day)	Exposure reduction (drone vs handheld)	Actual Exposure with gloves (mg/person/kg applied/day)	Exposure reduction (drone vs handheld)
Bayer Safety standard, handheld normal crop, application only	159.7	99.6%	10.9	96.3%	3.5	99.3%
Bayer Safety standard, Handheld dense crop	324.6	99.8%	50.3	99.2%	42.9	99.9%
AOEM, 75th centile, backpack, downwards	99.3	99.3%	10.5	96.1%	8.9	99.7%
AOEM, 75th centile, backpack, upwards	65.4	99.0%	3.9	89.7%	1.2	97.8%
CLI - Handheld backpack	N/A	N/A	29.4	98.6%	25.0	99.9%

Figure 3. Comparison of operator exposure between UAVs and backpack ssprayers (Kuster et al., 2023).

These findings highlight the potential of UAVs to decrease exposure risk, particularly during mixing and loading operations. However, it was noted that specific job steps unique to UAV operations require further investigation to fully understand their implications for operator exposure (Bonds et al., 2024). In conclusion, while UAV-assisted pesticide applications offer the potential to reduce operator exposure levels, further research is necessary to ensure the safe use of this emerging technology. It is crucial to promote the use of appropriate protective clothing and equipment among operators and to raise awareness regarding exposure risks.

Conclusion

This study emphasizes the critical importance of understanding operator exposure to pesticides during agricultural applications involving various types of sprayers, including field sprayers, vineyard and orchard sprayers, backpack sprayers, and Unmanned Aerial Vehicles (UAVs). The findings indicate that while field sprayers are effective for large-scale pesticide applications, vineyard and orchard sprayers provide precision in targeting specific areas, thus reducing unnecessary exposure. Backpack sprayers, on the other hand, offer maneuverability in confined spaces but may increase operator exposure due to their design and usage patterns.

The integration of UAV technology in pesticide application has demonstrated a significant potential to reduce operator exposure by approximately 90-99%, while also minimizing chemical usage. However, challenges remain in ensuring the safety and effectiveness of these advanced methods. This research underscores the necessity for comprehensive safety measures, including the consistent use of personal protective equipment

(PPE) and thorough training programs for operators to mitigate health risks associated with pesticide exposure.

Furthermore, the study highlights the need for ongoing research to develop innovative strategies and technologies that further minimize health risks linked to pesticide applications. The combination of field sprayers, vineyard and orchard sprayers, backpack sprayers, and UAVs represents a multifaceted approach to achieving safer agricultural practices. Ultimately, fostering a safer agricultural environment through these initiatives is essential for enhancing operator health and promoting environmental sustainability.

Conflict of Interest Statement

The author of the article declares that there is no conflict of interest.

Contribution Statement Summary

The author declares sole responsibility for the entirety of the article.

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