Uluslararası Tarım Araştırmalarında Yenilikçi Yaklaşımlar Dergisi
International Journal of Innovative Approaches in Agricultural Research 2025, Vol. 9 (2), 127-141
https://doi.org/10.29329/ijiaar.2025.1321.6


Original article

# Efficacy of UAV-Based Fungicide Applications in Managing Fusarium Head Blight in Wheat

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**Abstract**

Wheat (*Triticum aestivum L.*) production is significantly impacted by fungal diseases, with Fusarium head blight (FHB) posing a major threat due to yield loss and contamination with harmful mycotoxins such as deoxynivalenol (DON). The potential for UAVs to deliver precise, low-volume pesticide applications has generated significant interest, given their ability to enhance droplet penetration and coverage uniformity. This capability is particularly relevant as traditional methods often face limitations in ensuring consistent pesticide distribution, leading to suboptimal disease control and environmental concerns. Understanding the comparative performance of UAVs and conventional field sprayers (FS) under real agricultural conditions is critical for determining best practices and optimizing disease management strategies. This study investigated the efficacy of unmanned aerial vehicles (UAVs) compared to conventional field sprayers (FS) for fungicide application to control Fusarium head blight (FHB) in wheat fields in the Trakya region of Turkey. The UAV used was a DJI Agras MG-1P equipped with an 8-rotor system and a 4-nozzle setup producing droplet sizes between 106-235 μm, operated at a height of 2 meters, with a 20 L/ha spray rate and 11 km/h speed. The field sprayer employed was a tractor-mounted sprayer with 24 XR110003 nozzles on a 12-meter boom, spraying at a rate of 200 L/ha, 3 bar pressure, and a forward speed of 10 km/h. The field trials were conducted on 25x12 meter plots and each plot was artificially inoculated with Fusarium culmorum S-14 spores at 1x105 spores/ml during the flowering stage. Fungicide applications utilized a 125 g/L prothioconazole plus 125 g/L tebuconazole mixture (Prosaro EC 250), applied 48 hours post-inoculation. Control plots included non-treated infected spikes and fungicide-treated non-infected spikes (UAVC and FSC).

Disease severity and incidence were assessed 18 days post-application, and spike weight, kernel weight, and kernel numbers were measured at harvest. The data were analyzed using SPSS for statistical significance, employing ANOVA and post-hoc tests where appropriate. UAV applications yielded significantly lower disease severity (7.77%) and incidence (36.67%) compared to FS (16.73% and 46.67%, respectively), with superior agronomic performance in spike weight (1.80 g), kernel weight (1.36 g), and kernel number (35.53). These results underscore the advantages of UAVs in achieving effective, uniform fungicide coverage and reducing environmental impact, supporting their potential as a sustainable alternative to traditional pesticide application methods in agriculture. Further research is recommended to fine-tune UAV operational parameters for broader agricultural applications.

**Keywords:** Unmanned Aerial Vehicle, Field Sprayer, Fusarium Head Blight, Fungicide, Pesticide, Wheat.

**Received:** 03 November 2024 * **Accepted:** 08 June 2025 * **DOI:** https://doi.org/10.29329/ijiaar.2025.1321.6

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## INTRODUCTION

Wheat (*Triticum aestivum L.*) is one of the most important cultivated cereals in the world, accounting for about 30% of total world wheat production (FAO, 2023). However, Wheat is treated by different fungal pathogens, losing 21.5% of wheat production to these diseases annually. Globally, Leaf rust is the most economically damaging disease of wheat followed by Fusarium head blight (Scherm et al., 2013; Savary et al., 2019). Fusarium head blight (FHB) is caused by different Fusarium species such as *F. culmorum* and *F. graminearum* (Parry et al., 1995; Summerell, 2019) which leads to contamination of wheat kernels with deoxynivalenol (DON), comprising serious risks to human and animal health (Xiao et al., 2019). It is known that *F. culmorum* is a widespread pathogen in the Trakya region (Hekimhan, 2010) and also secretes the important mycotoxin DON (Pasquali et al., 2016). Köycü 2022 also showed that correct fungicide selection and timing are effective in reducing mycotoxins (especially deoxynivalenol - DON) in head blight of wheat in the Trakya Region (Köycü, 2022). This critical role of fungicides not only controls the disease but also benefits food safety by reducing the accumulation of mycotoxins in cereals. The growing season and nutritional quality represent a pivotal aspect of effective FHB management (Zhou et al., 2023). The control of Fusarium head blight (FHB) relies on the use of chemical fungicides, including demethylation inhibitor (DMI) fungicides. These include metconazole, prothioconazole, tebuconazole, and prothioconazole plus tebuconazole (Mesterházy et al., 2011; McMullen et al., 2012). Paul et al. (2018) found that the effectiveness of tebuconazole, pyraclostrobin, and prothioconazole can be affected by factors such as the timing of application and application technique.

In recent years, advances in pesticide application technology have emerged as a promising solution to enhance the efficiency of fungicide application and minimize environmental risks. Among these innovations, unmanned aerial vehicles (UAVs) have attracted attention as a potential improvement in pesticide application due to their high reliability, reduced operating pressure requirements, and rear sensitivity (Xiao et al., 2019). In recent years, using fungicides by unmanned aerial vehicles (UAV) in agricultural disease management has become increasingly prevalent. Zhou et al. (2023) demonstrated the efficacy of UAVs in the control of Fusarium spike blight, emphasizing the importance of droplet distribution and penetration. The study demonstrated that treatments using UAVs were more effective and environmentally sustainable than those using conventional field sprayers. Moreover they found that plant protection UAVs in China demonstrated high operational efficiency, with pesticide-mixture utilization rates above 50% and labor productivity of 5.75 ha per man-hour, significantly surpassing the knapsack sprayer. UAVs achieved over 90% control efficacy for wheat Fusarium head blight and a comprehensive performance score of 0.812 (a composite score that integrates multiple criteria such as disease control efficacy, operational efficiency, environmental sustainability, and overall productivity in agricultural practices) , positioning them as an effective alternative to traditional methods. These findings highlight UAVs' potential to enhance pesticide application efficiency and disease control in agriculture. Zhang et al. (2021) highlighted the effectiveness of UAVs in pest and disease control when flight speed and flight height parameters are optimized. Results showed that flight speed significantly impacted the effective spraying width, while both flight height and its interaction with flight speed influenced droplet deposition uniformity, leading to strong control outcomes for wheat aphids and fungal diseases. This research supports the importance of precise parameter adjustments to enhance UAV performance in modern crop protection. The adoption of UAVs for agricultural applications is occurring rapidly due to the flexibility and operational advantages they offer. Unmanned aerial vehicles (UAVs) offer several advantages over traditional methods, including improved droplet penetration, uniform application, and reduced pesticide loss (Abbas et al., 2023). It has been demonstrated that UAVs can provide control of diseases such as Fusarium head blight (Zhou et al., 2019), powdery mildew (Qin et al., 2018), soybean rust (Soares et al., 2024), and leaf sheath blight (Wiangsamut et al., 2024) that is equal to or superior to that achieved by traditional ground and boom sprayers. Furthermore, UAVs facilitate increased pesticide application rates by ensuring uniform distribution throughout the crop canopy and reducing wastage. Nevertheless, despite the encouraging outcomes of UAV-based pesticide application, the impact of disparate UAV models and application parameters on FHB and mycotoxin contamination remains unclear. Fungicide efficiency depends on spike coverage during application, which is affected by the nozzle type, and spray angle (Mesterházy et al., 2011). As UAV technology advances, additional assessment is essential to ascertain the optimal configuration to optimize pesticide efficacy while minimizing environmental impact and ensuring food safety. (Abbas et al., 2023). Spray rate is one of the most crucial factors that affects coverage and droplet distribution uniformity and as Önler et al. (2023) stated, it should be a minimum of 20 l/ha for pesticide applications. The commonly used pesticide application equipment (PAE) in Turkiye mainly includes traditional field sprayers (Özyurt et al., 2020). Several studies have demonstrated the efficacy of unmanned aerial vehicle (UAV) applications in the management of Fusarium head blight. For sustainable agriculture, environmental protection, less water, pesticides and fossil fuels, labour and time are the main savings mentioned in all studies.

However, there remain knowledge gaps regarding the performance of this technology under different operational parameters, including spray speed, altitude, droplet size, and environmental conditions. This study aims to address these questions through field trials conducted in the Trakya region of Turkey, with a particular focus on evaluating the performance of UAVs under local agricultural conditions, thereby contributing to the existing literature on this topic. This study also aims to compare the fungicide application efficiency of unmanned aerial vehicles (UAV) and conventional field sprayers (FS) in controlling Fusarium head blight (FHB) disease in wheat fields and to evaluate the differences between these two methods in terms of disease severity (%), disease rate (%), spike weight (g), grain weight (g) and grain number. The study intends to investigate the effectiveness of UAV spraying technology in reducing the severity and rate of FHB disease and to explore the potential benefits of this technology in agricultural production.

## MATERIALS and METHODS

### UAV and FS Equipments

**UAV (Unmanned Aerial Vehicle):** In the experiment, a DJI Agras MG-1P UAV with an 8-rotor, 4-nozzle system and a 10-liter tank was used for spraying. TeeJet XR 11001VS nozzles, arranged at the corners of a square, produced droplet sizes of 106-235 µm. The UAV's flight and spraying parameters were controlled remotely (Table 1). Target parcel locations were mapped, and flight routes were generated automatically. The UAV sprayed at 2 meters height, 20 L/ha rate, and 11 km/h speed (Önler et al., 2023). Spraying started and stopped 5 meters from the parcel boundaries to avoid affecting mammal-related experiment data. RTK (Real-Time Kinematics) technology was used for precise location accuracy.

**FS (Field Sprayer):** The field sprayer used in the experiment is a tractor-mounted model with an 800-liter tank, a membrane pump, and 24 XR110003 nozzles on a 12-meter boom, commonly used in the Trakya region of Turkey. Spraying is performed at a fixed speed, pressure, and rate, starting from the middle of the plot and ending at the plot's boundary. Spraying was carried out with a spraying rate of 200 L/ha at 3 bar pressure, and a tractor speed of 10 km/h. 200 L/ha spray rate is suggested by pesticide companies, and pressure and forward speed is both suggested by the nozzle manufacturers and preferred as local farmers (Özyurt et al., 2020). In the wheat field, the spraying parameters of UAV and FS are shown in Table 1.

**Table 1.** Spraying Parameters of UAV and FS in the wheat plots.

| Spraying Equipment | UAV | FS |
|---|---|---|
| Tank Capacity (l) | 10 | 1000 |
| Nozzle Type | XR11001VS | AIXR11003 |
| Droplet Spectra (µm) | 106-235 | 400-700 |
| Pressure (bar) | 3.5 | 3 |
| Forward speed (km/h) | 11 | 10 |
| Application height (m) | 2 | 0,5 |
| Spray Rate (L/ha) | 20 | 200 |

### Field Trials

The field trial was conducted at the trial area of Tekirdağ Namık Kemal University in the 2021-2022 season (40°59'30.25"N 27°35'3.97" E). The bread wheat variety "Flamura 85", previously found to be susceptible to *Fusarium culmorum*, was used in the trial (Köycü and Özer, 2019). For each plot, the main spikes of 10 individual wheat crops were artificially inoculated with $1x10^5$ spores/ml of

*Fusarium culmorum* S-14 (Pasquali et al., 2016) isolate in the flowering stage (ZGS61; Zadoks et al., 1974). The fungicide (125 g/L prothioconazole plus 125 g/L tebuconazole a.i; Prosaro EC 250 Bayer CropScience), licensed for head blight was applied 48h after spike inoculation of *F. culmorum* by UAV or FS. Control spikes were only infected by *F. culmorum*. To stimulate the growth of infection, the spikes were treated with water in the morning and evening for two days. The trial plots were formed as follows. Infected spike control (IC) (spikes inoculated with the pathogen alone), infected +UAV fungicide application (UAV), infected +field sprayer fungicide application (FS), non-infected +UAV fungicide application (UAVC), non-infected +FS fungicide application (FSC) and general control (GC) (non-infected spikes with no fungicide application). The placement of the trial plots in the field was determined by the randomized block method with three replicates.

The wheat seed was applied with a fungicide containing 40 g of pyraclostrobin plus 80g of triticonazole a.i. (Insure Perform FS, BASF). A licensed fungicide containing 250 g/L prochloraz plus75 g/L trifloxystrobin plus 50 g/L cyproconazole a.i. (Basking 100 ml/da Agrobest Turkey) active ingredient was applied to control root and crown rot disease in wheat during the growth stage ZGS 27 (20 March 2022) (Zadoks et al., 1974). During the application, the temperature was measured as 15 degrees Celsius, the humidity was 69%, and the wind speed was 5.1 km/h. Meteorological data were collected during the application using a Lutron AM 4202 model anemometer and a Testo brand 605-H1 thermo-hygrometer at a height of 2 meters, and averages were taken.

The size of each plot was determined at 25x12 meters to facilitate maneuverability, RTK positioning accuracy, and uniformity of UAV and FS applications. Since the 12-meter width is equal to the working width of the field sprayer, the field sprayer can be used to apply the treatment in a single pass in the plots where the field sprayer is used. A 10-meter space was left at the top and bottom of the plot for the UAV's take-off, landing, and turning maneuvers, for the tractor to maneuver. A 12-meter gap was left between the two plots to minimize the effect of spray drift, and wheat was sown in 25x6 meter plots in these areas as a buffer zone (Figure 1).

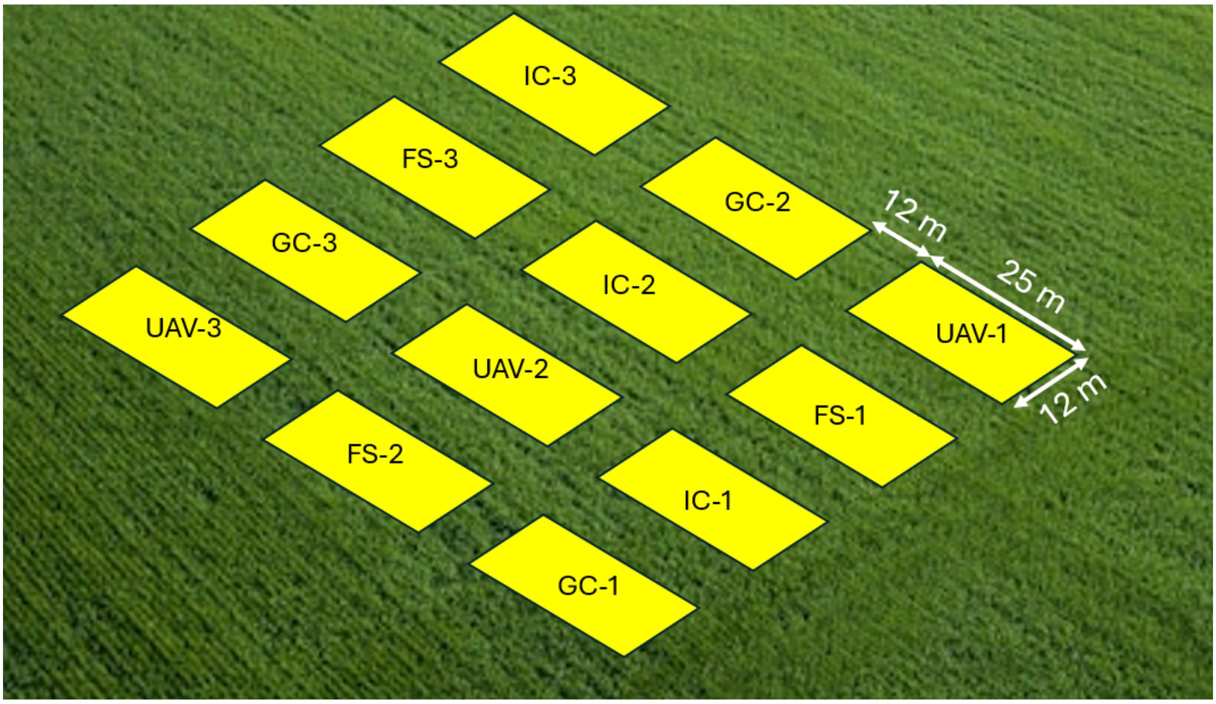


**Figure 1.** Layout of test plots

The sowing rate was 180 kg/ha, and the spacing between rows was 13 cm. Plant protection and fertilization practices were carried out as in conventional wheat cultivation throughout the growing season. Before sowing, 200 kg/ha of 12-20-0 NPK organomineral fertilizer was used as a base fertilizer. Pyroxasulfone (Kelt WG 85, Bayer Crop Science), an effective pre-emergence herbicide, was applied to control weeds after sowing. During the growing season, 150 kg/ha of 46% urea fertilizer was applied on 5 March 2022, and 150 kg/ha of 46% urea was applied on 4 April 2022.

In the disease severity assessment, infected spikes with/without fungicide treatment were selected from 10 main plants in each plot, and *F. culmorum* head blight was determined according to 0-100% scale after the 18th day (Stack and McMullen, 2011). Disease severity (%) was determined (Disease Severity = Σ (n. V) $Z * N * 100$) (n: number of samples with different disease degrees on the scale; V: Scale value; Z: Highest scale value, N: Total number of samples observed) (Townsend and Heuberger, 1943). The disease rate (%) was determined based on the percentage value of the ratio of the number of infected spikes to the total number of spikes. The efficacy (%) of fungicide application with UAV and FS was determined as Percent effect = (IC-(UAV or FS)/IC)*100.

For harvest assessment, 25 plants were taken from each experimental plot and the spike height (cm), kernel weight (cm) and kernel numbers were measured.

**Statistical Analysis**

The data were analyzed statistically using the statistical software package SPSS (Version 18, IBM Corp., Armonk, NY). A one-way analysis of variance (ANOVA) was conducted to assess the statistical significance of the differences between the experimental groups. In the case of non-parametric data, the Mann-Whitney U test was employed. Furthermore, an independent samples t-test was employed to assess the discrepancy in means between the two groups.

## RESULTS

Disease severity (%) and disease rate (%) detected after fungicide application with UAV and FS and in the infected control are given (Table 2). Disease severity (%) and disease rate (%) were lower and more effective (85.21%-68.16%) after fungicide treatment with UAV than FS. These results show that UAV application has a significant effect in reducing disease rate and severity.

**Table 2.** Disease severity (%), disease rate (%), and percentage efficacy (%) of fungicides on *F. culmorum* infected spikes treated with UAV and FS and non-fungicide treated (IC) spikes in the field.

| **Percentage (%)** | | | | **Percent Effect (%)** | |
|---|---|---|---|---|---|
| | UAV | FS | IC | UAV | FS |
| **Disease severity** | 7.77* | 16.73 | 52.55 | 85.21 | 68.16 |
| **Disease incidence** | 36.67 | 46.67 | 66.67 | 44.99 | 29.99 |

* Each value is the average of 10 wheat ears in each plot in the field.

The distribution of basic agronomic characteristics such as spike weight, number of kernels, and kernel weight in the data analyzed in the study is given in Figure 2.

The average spike weight in the UAV-treated group was 1.80 g, ranging from 0.96 to 2.78 g, with the majority of values concentrated between 1.44 and 2.18 g, indicating medium to high spike weights. In the FS-treated group, the mean spike weight was 1.41 g, with values ranging from 0.61 to 2.50 g, and most weights clustered between 1.08 and 1.70 g, reflecting medium-level distributions. The control group exhibited generally lower spike weights, averaging 1.14 g, with a range from 0.54 to 2.34 g and most values between 0.85 and 1.31 g. The GC group had the highest spike weights, averaging 2.08 g, with a range of 0.76 to 3.15 g and a concentration between 1.74 and 2.42 g. Overall, the GC group recorded the highest spike weight values, while the control group showed the lowest. Both UAV and FS treatments resulted in intermediate spike weights, with UAV application achieving a higher mean compared to FS. Additionally, the average spike weight for the UAVC group was 1.99 g (0.74–2.90 g), while that for the FSC group was 1.95 g (0.67–3.20 g).

The average kernel weight in the UAV-treated group was 1.36 g, with values ranging from 0.53 to 2.20 g, and the majority concentrated between 1.01 and 1.74 g. This distribution indicates medium to high kernel weights. In the FS-treated group, kernel weight averaged 0.95 g, varying between 0.12 and 1.91 g, with most values falling between 0.66 and 1.21 g. In the control group, the average kernel weight was lower at 0.60 g, ranging from 0.02 to 1.83 g, with most values clustered between 0.24 and 0.75 g. The GC group exhibited the highest average kernel weight at 1.63 g, with a range of 0.48 to 2.48 g and a concentration between 1.39 and 1.92 g. Overall, the GC group recorded the highest kernel weights, while the control group had the lowest. Comparing UAV and FS treatments, UAV demonstrated a higher mean kernel weight. For the UAVC group, the average kernel weight was 1.55 g (0.56–2.50 g), while in the FSC group it was 1.49 g (0.52–2.28 g).

The average number of kernels per spike in UAV-treated group is 35.53. The minimum number of kernels was 10 and the maximum number of kernels was 70. The majority of the data were concentrated between 28.75 and 43. This group generally has high values in terms of the number of kernels in the spike. The average number of kernels in the FS group was 25.12. The minimum number of kernels is 12 and the maximum is 43. Most of the values are concentrated between 18.5 and 33. The FS group has medium values in terms of kernel number and shows a low to medium distribution compared to the other groups. The average number of kernels in the control group was 18.53, which is considerably lower than the other groups. The minimum number of kernels was 1 and the maximum number was 51. Most of the data are concentrated between 10 and 27. The average number of kernels in GC has the highest value at 42.23. The minimum number of kernels is 20 and the maximum is 58. Most values are concentrated between 39 and 44.5. The number of kernels in the GC group is generally concentrated at high levels. As a result, GC has the highest number of kernels and the control has the lowest number of kernels. The UAV group shows high kernel counts, while the FS group is more moderate. In the UAVC group, the average kernel count was 40.47, ranging between 18-57 kernels, and in the FSC group, it averaged 37.27 kernels, varying between 16-55 kernels.

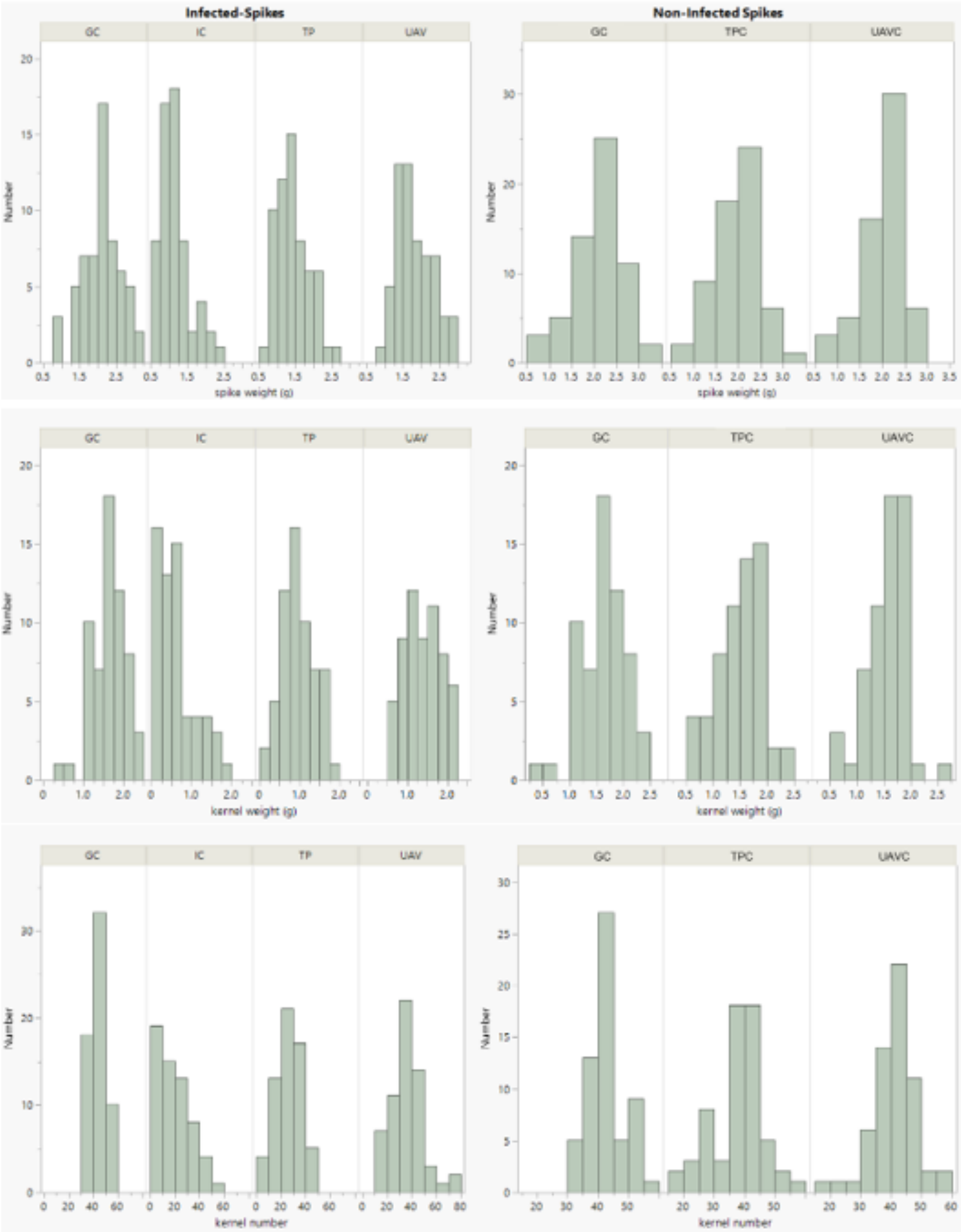


**Figure 2.** Scatter plots of spike weight (g), kernel weight (g), and number of kernels. C: infected with pathogen and no fungicide application; GC: not infected with pathogen and no fungicide application; UAV: infected with pathogen and fungicide application; FS: infected with pathogen and fungicide application

There was a statistically significant ($p<0.0001$) difference between UAV and FS groups in spike weight, kernel weight, and kernel number (Figure 3). The UAV group had higher values in terms of spike weight, kernel number, and kernel weight compared to the FS group. This shows the positive effect of UAV applications. The box plots for spike weight and kernel weight demonstrate a concentration of values in the upper quartiles, indicating a tendency toward higher measurements. In contrast, the distribution of the number of kernels showed greater variability, with a wider interquartile range and increased dispersion. These variations could potentially be attributed to differences in pesticide application timing or droplet density, which are known to influence pesticide deposition, spike coverage, and ultimately yield components. Further investigation into the relationship between application parameters and yield variability is warranted.

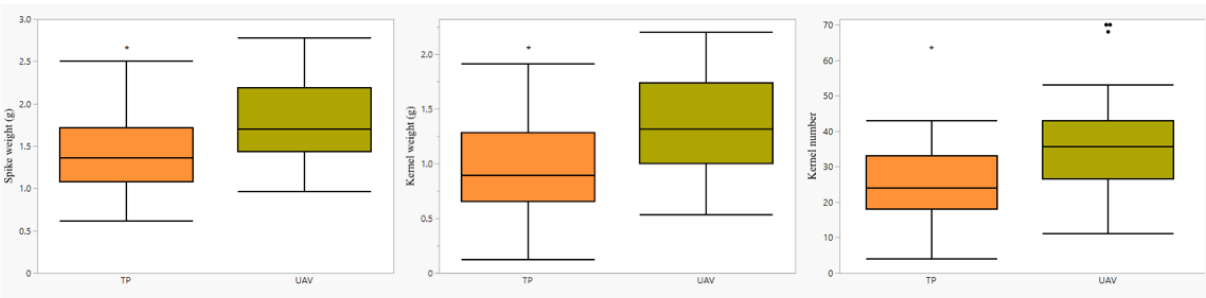


**Figure 3.** Box plots of spike weight (g), kernel weight (g), and number of kernels obtained as a result of UAV and FS fungicide treatments on F. culmorum infected spikes.

In the graph, the lower and upper borders of the boxes represent the 25th and 75th percentiles of the data, respectively, while the thick line inside the box indicates the median value. The width of each box summarises the distribution and variability of the data. Outliers observed in the graphs represent values that deviate from the general distribution of the data and are unusually high or low relative to other data points. The differences between the UAV and FS treatments were determined to be statistically significant ($p<0.001$) by t-test.

**Non-infected spikes**

In the study, agronomic characteristics, including kernel number, spike weight, and kernel weight, were quantified across different groups (UAVC, FSC, and GC) (Figure 4). The results demonstrated a statistically significant difference ($p = 0.008$) between the groups in terms of the number of kernels. No statistically significant difference was observed between the groups with spike weight and kernel weight. Consequently, the UAV-based treatments resulted in a notable increase in the number of kernels, while there was no statistically significant difference observed in spike weight and kernel weight of non-infected spikes.

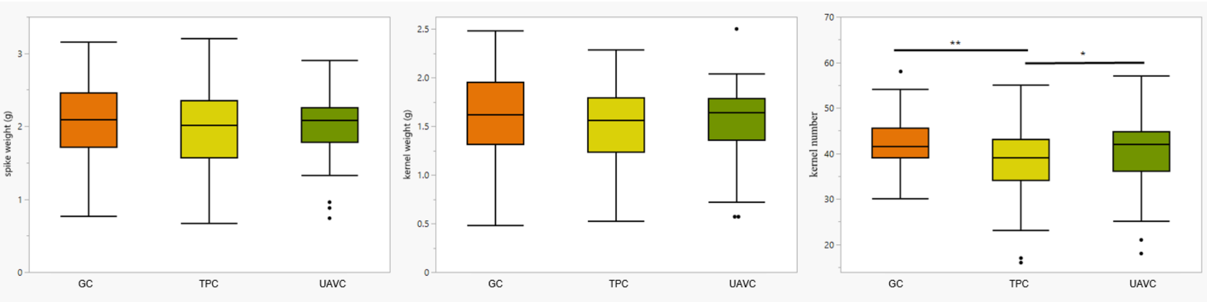


**Figure 4.** Box plots of spike weight (g), kernel weight (g), and number of kernels in *F. culmorum* non-infected spikes treated with UAVC and FSC and non-fungicide treated (GC) spikes.

In the graph, the lower and upper borders of the boxes represent the 25th and 75th percentiles of the data, respectively, while the thick line inside the box indicates the median value. The width of each box summarises the distribution and variability of the data. Outliers observed in the graphs represent values that deviate from the general distribution of the data and are unusually high or low relative to other data points. Differences between UAVC, FSC, and GC were determined to be statistically significant * ($p<0.05$), **($p<0.001$) by t-test.

## DISCUSSION

These findings confirm that UAVs have significant potential to increase agricultural productivity when compared with the existing literature. It shows that hyperspectral imaging technology is effective in FHB control of UAVs and makes a great contribution to early diagnosis and monitoring processes (Liu et al., 2020; Ma et al., 2021). The findings of this study accord with the existing literature, which emphasizes the efficacy of unmanned aerial vehicle (UAV) fungicide applications in controlling Fusarium head blight (FHB). Zhang et al. (2021) emphasized that UAVs surpass traditional methods in agricultural disease control by providing more uniform application and ensuring more efficient pesticide use (Zhang et al., 2021). This study further supports these findings, showing that UAV applications significantly reduce disease severity compared to conventional field sprayers. However, further research is required to assess the impact of different UAV models and application parameters on FHB control. In our study, fungicide application with UAV applications significantly reduced Fusarium head blight disease severity and rate compared to conventional FS. The results of Zhang et al. (2021) show that UAVs offer high success (90%), especially in common diseases such as FHB. This result was achieved through better observation of the disease and more accurate application of fungicides. At the same time, Wang et al. (2019) reported that UAVs provided better pesticide distribution at volumes of 16.8 L/ha and 28.1 L/ha, and the highest disease control rates of wheat powdery mildew were obtained at these volumes. Xiao et al. (2019) showed that UAV increased disease control efficacy by 14.2% to 19.6% with 48% phenamacril-tebuconazole application. This is an important advantage in terms of maintaining yield by reducing disease spread. Yan et al. (2021) found that prothioconazole was applied with UAV-controlled Fusarium head rot (FHB) by 96.64%, while the addition of adjuvant increased this rate to

99.16%. This shows that the use of adjuvant increases the control efficiency against diseases and pests. These results of the researchers are consistent with our study. In our study, both spike weight and kernel weight were found to be higher in fungicide application with UAV during the flowering period to pathogen-infected spikes compared to FS. These findings support studies by Wang (2019) and Zhou (2023) that UAVs have positive effects on plant yield as they provide more homogeneous pesticide distribution and reduce chemical losses (Wang et al., 2019; Vitória et al., 2023). The ability of UAVs to perform low-volume spraying can increase environmental sustainability. The study of Fritz et al. (2007) shows that UAVs increase chemical deposition on wheat ears and increase productivity. UAVs minimize environmental impacts with lower pesticide loss in agricultural applications. The fact that similar or better results can be achieved despite using fewer chemicals compared to conventional methods shows that UAVs offer a sustainable alternative in agriculture (Wang et al., 2019). In this study, it was observed that UAV applications gave better results with less fungicide use and lower environmental impact compared to FS. This is in line with the study of Fritz et al. (2007), who confirmed that UAVs optimize pesticide use with low-volume spraying systems that support environmental sustainability. The lower disease severity observed with UAV applications may be attributed to the device's ability to provide more precise spraying and minimize pesticide losses (Xiao et al., 2019). It is suggested that UAV applications allow for a more uniform distribution of pesticides on the plant surface, resulting in more effective pathogen control (Zhang et al., 2021). Additionally, our results obtained with the UAVC and FSC applied to non-infected spikes showed notable findings compared with the control group (GC) that had not been treated with fungicide. The increase in kernel number observed in the UAVC and FSC indicates that these technologies can contribute to yield potential even in the absence of infection. However, no significant difference was observed between the groups in terms of spike weight and kernel weight. A comparison of UAVC and FSC treatments with the GC indicates the potential of these technologies to enhance yield even in non-infected spikes. In the present study, XR11001VS nozzles (fine droplet spectrum) were used for UAV applications and AIXR11003 nozzles (very coarse droplet spectrum) for field sprayers. Previous studies, such as those by Zhang et al. (2021) and Xiao et al. (2019), employed flat-fan nozzles or air induction nozzles with varying droplet sizes. Differences in nozzle type can significantly affect droplet size, spray deposition, and coverage, thereby influencing the efficacy of disease control. These differences should be considered when comparing the present results with those reported in the literature.

Although this study primarily focused on biological outcomes such as spike and kernel characteristics, it is important to consider the potential influence of pulverization characteristics on these results. The XR11001VS nozzles used for UAV applications produced droplet sizes ranging from 106 to 235 µm, categorized as fine to medium droplets, which are favorable for better canopy penetration and uniform coverage. In contrast, the AIXR11003 nozzles employed in the field sprayer generated larger droplets ranging from 400 to 700 µm, classified as very coarse to extremely coarse, designed to minimize drift but often resulting in less canopy penetration. These differences in droplet size distribution could have contributed to the observed variations in disease control efficacy and yield parameters. However, direct measurements of spray deposition and coverage were not conducted in this study. Future research should integrate in-situ spray quality assessments to better elucidate the relationship between pulverization dynamics and biological outcomes.

## CONCLUSION

This study reveals that unmanned aerial vehicles (UAVs) offer an effective alternative to conventional field spraying systems (FS) for the control of Fusarium head blight (FHB). UAVs stand out with less environmental impact and higher labor productivity while achieving significant success in disease control. Unmanned aerial vehicles (UAVs) offer many advantages compared to conventional methods with less labor requirement, faster application, and less environmental impact. In addition, more extensive studies should be carried out in different geographical conditions and crops to ensure high efficiency. This study shows that UAVs offer a more effective solution for controlling FHB and increasing wheat productivity compared to conventional methods. UAVs offer lower environmental impact, high disease control rate, and better productivity while optimizing pesticide use and increasing environmental sustainability. These results show that UAVs have an important future in agricultural disease management in Turkey and the world. Further detailed studies are required to determine the optimal parameters for the operation of unmanned aerial vehicles (UAVs) in agricultural settings. While the field trials conducted in the Trakya region of Turkey offer valuable insights into the potential of UAV technology in this region, additional research is necessary to fully understand the scope of its applicability across different climatic and agricultural contexts.

**Acknowledgment**

The authors thank the student team members Arife Adak, Cagatay Dayan, Alara Uzuner, Kemal Çelik, Aysenur Topcu, and Gurkan Simsek for their important contributions.

## REFERENCES

Abbas, A., Zhang, Z., Zheng, H., Alami, M. M., Alrefaei, A. F., Abbas, Q., & Zhou, L. (2023). Drones in plant disease assessment, efficient monitoring, and detection: A way forward to smart agriculture. Agronomy, 13(6), 1524.

Fritz, B. K., Hoffmann, W. C., Martin, D. E., & Thomson, S. J. (2007). Aerial application methods for increasing spray deposition on wheat heads. Applied Engineering in Agriculture, 23(6), 709-715.

Anonymous. (2023). Wheat production statistics. Retrieved from [https://www.fao.org/statistics/en/]

Hekimhan, H. (2010). Researches on fungi caused root and crown rot of wheat, and some factors affecting its pathogenicity in the Trakya region. Graduate School of Natural and Applied Science of Selçuk University, Degree of Doctor of Philosophy in Plant Protection, Selçuk/Turkey, 134 p.

Köycü, N. D., & Özer, N. (2019). Trakya Bölgesi'nde bazı buğday çeşitlerinin Fusarium spp. izolatlarına karşı dayanıklılığın tespit edilmesi. KSU Journal of Agriculture and Nature, 22(4), 498-505.

Köycü, N. D. (2022). Effect of fungicides on spike characteristics in winter wheat inoculated with Fusarium culmorum. *Food Additives and Contaminants: Part A*, *39*(5), 1001-1008.

Liu, L., Dong, Y., Huang, W., Du, X., & Ma, H. (2020). Monitoring wheat fusarium head blight using unmanned aerial vehicle hyperspectral imagery. Remote Sensing, 12(22), 3811.

Ma, H., Huang, W., Dong, Y., Liu, L., Guo, A. 2021. Using UAV-based hyperspectral imagery to detect winter wheat fusarium head blight. *Remote Sensing*, *13*(15), 3024.

McMullen, M.; Bergstrom, G.; de Wolf, E.; Dill-Macky, R.; Hershman, D.; Shaner, G.; van Sanford, D. A. 2012. Unified Effort to Fight an Enemy of Wheat and Barley: *Fusarium* Head Blight. *Plant Dis. 96*, 1712–1728.

Mesterházy, Á., Tóth, B., Varga, M., Bartók, T., Szabó-Hevér, Á., Farády, L., & Lehoczki-Krsjak, S. (2011). Role of fungicides, application of nozzle types, and the resistance level of wheat varieties in the control of Fusarium head blight and deoxynivalenol. *Toxins*, *3*(11), 1453-1483.

Parry, D.W.; Jenkinson, P.; McLeod, L. 1995. *Fusarium* Ear Blight (Scab) in Small Kernel Cereals—A Review. *Ptant Pathol. 44*, 207–238.

Pasquali, M., Beyer, M., Logrieco, A., Audenaert, K., Balmas, V., Basler, R., Boutigny, A.-L., Chrpová, J., Czembor, E., Gagkaeva, T., González-Jaén, M. T., Hofgaard, I. S., Köycü, N. D., Hoffmann, L., Lević, J., Marin, P., Miedaner, T., Migheli, Q., Moretti, A., Müller, M. E. H., Munaut, F., Parikka, P., Pallez-Barthel, M., Piec, J., Scauflaire, J., Scherm, B., Stanković, S., Thrane, U., Uhlig, S., Vanheule, A., Yli-Mattila, T., & Vogelgsang, S. (2016). A European database of Fusarium graminearum and F. culmorum trichothecene genotypes. Frontiers in Microbiology, 7, 406. https://doi.org/10.3389/fmicb.2016.00406

Paul, P. A., Bradley, C. A., Madden, L. V., Dalla Lana, F., Bergstrom, G. C., Dill-Macky, R., Esker, P. D., Wise, K. A., McMullen, M., Grybauskas, A., Kirk, W. W., Milus, E., & Ruden, K. (2018). Meta-analysis of the effects of QoI and DMI fungicide combinations on Fusarium head blight and deoxynivalenol in wheat. Plant Disease, 102(12), 2602–2615. https://doi.org/10.1094/PDIS-02-18-0211-RE

Qin, W., Xue, X., Zhang, S., Gu, W., & Wang, B. (2018). Droplet deposition and efficiency of fungicides sprayed with small UAV against wheat powdery mildew. *International Journal of Agricultural and Biological Engineering*, *11*(2), 27-32. https://doi.org/10.25165/j.ijabe.20181102.3157

Önler, E., Özyurt, H. B., Şener, M., Arat, S., Eker, B., & Çelen, İ. H. (2023). Spray characterization of an unmanned aerial vehicle for agricultural spraying. The Philippine Agricultural Scientist, 106(1), 39-46.

Özyurt, H. B., Onler, E., & Celen, I. H. (2020). Determination of the field sprayers and their problems in Thrace Region, Turkey. International Journal of Innovation Engineering and Science Research, 4(6), 68-73.

Stack, R., & McMullen, M. (2011). A visual scale to estimate severity of fusarium head blight in wheat. NDSU Extension Service, Fargo, ND. PP-1095.

Savary, S., Willocquet, L., Pethybridge, S. J., Esker, P., McRoberts, N., & Nelson, A. (2019). The global burden of pathogens and pests on major food crops. Nature Ecology & Evolution, 3, 430–439.

Scherm, B., Balmas, V., Spanu, F., Pani, G., Delogu, G., Pasquali, M., & Migheli, Q. (2013). Fusarium culmorum: Causal agent of foot and root rot and head blight on wheat. Molecular Plant Pathology, 14(4), 323–341.

Soares, R. M., Adegas, F. S., & Roggia, S. (2024). *Drone Spraying of Fungicides to Control Asian Soybean Rust*. https://doi.org/10.2139/ssrn.4781017

Summerell, B. A. (2019). Resolving fusarium: Current status of the genus. Annual Review of Phytopathology, 57, 323–339.

Townsend, G. K. J. W., & Heuberger, J. W. (1943). Methods for estimating losses caused by diseases in fungicide experiments. Plant Disease Reporter, 27, 340-343.

Vitória, E. L. D., Krohling, C. A., Borges, F. R. P., Ribeiro, L. F. O., Ribeiro, M. E. A., Chen, P., & Furtado Júnior, M. R. (2023). Efficiency of fungicide application using an unmanned aerial vehicle and pneumatic sprayer for control of Hemileia vastatrix and Cercospora coffeicola in mountain coffee crops. Agronomy, 13(2), 340.

Wang, G., Lan, Y., Qi, H., Chen, P., Hewitt, A., & Han, Y. (2019). Field evaluation of an unmanned aerial vehicle (UAV) sprayer: Effect of spray volume on deposition and the control of pests and disease in wheat. Pest Management Science, 75(6), 1546-1555.

Wiangsamut, B., Anutrakinchai, S., Makhonpas, C., Wiangsamut, M. E., & Thongkamngam, T. (2024). Efficiency of AI drone, air-blast, and long hose pump sprayers in spraying fungicide to manage leaf sheath blight caused by Rhizoctonia solani in durian. International Journal of Agricultural Technology, 20(4), 1687-1708.

Xiao, Z., Dong, H., Bai, L., Wu, D. O., & Xia, X. G. (2019). Unmanned aerial vehicle base station (UAV-BS) deployment with millimeter-wave beamforming. IEEE Internet of Things Journal, 7(2), 1336-1349.

Yan, X., Wang, M., Zhu, Y., Shi, X., Liu, X., Chen, Y., & Yuan, H. (2021). Effect of aviation spray adjuvant on improving control of fusarium head blight and reducing mycotoxin contamination in wheat. Agriculture, 11(12), 1284.

Zadoks, J. C., Chang, T. T., & Konzak, C. F. (1974). A decimal code for the growth stages of cereals. Weed Research, 14, 415–421.

Zhang, S., Qiu, B., Xue, X., Sun, T., Gu, W., Zhou, F., & Sun, X. (2021). Effects of crop protection unmanned aerial system flight speed, height on effective spraying width, droplet deposition and penetration rate, and control effect analysis on wheat aphids, powdery mildew, and head blight. Applied Sciences, 11(2), 712.

Zhou, Q., Zhang, S., Xue, X., Cai, C., & Wang, B. (2023). Performance evaluation of UAVs in wheat disease control. Agronomy, 13(8), 2131.