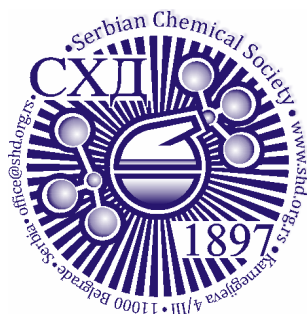




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Dissipation kinetics of boscalid and pyraclostrobin in strawberries: Implications for pre-harvest intervals and residue management

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Abstract: This study investigated the dissipation kinetics of the fungicides boscalid and pyraclostrobin in strawberries under field conditions. Residue analyses were performed using a validated modified QuEChERS extraction followed by GC-MS and HPLC-DAD quantification. Boscalid and pyraclostrobin exhibited half-lives of 3.89 and 2.40 days, respectively, indicating low persistence and first-order kinetic behavior. These results are in good agreement with previous studies in berry fruits and other crops, highlighting the influence of environmental factors such as temperature, solar radiation, and fruit surface characteristics on pesticide degradation. Pre-harvest intervals (PHIs) calculated from the regression models were 4.8 days for boscalid and 2.7 days for pyraclostrobin, supporting compliance with EU maximum residue limits. The findings confirm the reliability of the analytical method and provide valuable data for regulatory monitoring, dietary risk assessment, and sustainable pesticide management in soft fruit production.

Keywords: fungicides; berry fruits; dissipation; half-life; gas chromatography; liquid chromatography.

INTRODUCTION

The strawberry (*Fragaria* × *ananassa* Duch.), a hybrid species within the *Fragaria* genus of the *Rosaceae* family, is one of the most economically significant berry crops cultivated worldwide. Its distinctive flavour, colour, and aroma make it highly desirable to consumers, while its nutritional composition contributes to its importance in human diets. Strawberries are rich in vitamin C, folate, and essential minerals such as potassium, manganese, and magnesium, and they contain diverse bioactive phytochemicals, including flavonoids, phenolic acids,

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and ellagitannins, which exhibit antioxidant, anti-inflammatory, and antiproliferative properties.¹

Global strawberry cultivation covered approximately 397,000 ha in 2022, with a total production of around 9.6 million tonnes. China, the United States, and Turkey are the leading producers.² Despite their nutritional and economic importance, strawberries are particularly susceptible to fungal diseases such as *Botrytis cinerea* (grey mould), *Sphaerotheca macularis* (powdery mildew), and *Fusarium* spp. (root rot), as well as insect pests including *Tetranychus urticae* and *Frankliniella occidentalis*. These biotic stressors significantly reduce both yield and fruit quality.³

To control such pathogens and pests, fungicides and insecticides are routinely applied. However, the overuse or misuse of pesticides can result in undesirable residue levels in fruits, potentially causing harmful effects on human health and the environment.^{4,5} Pesticides have been associated with various toxicological mechanisms, including oxidative stress, endocrine disruption, and genotoxicity.⁶

In the European Union (EU), pesticide residues in food and feed are strictly regulated under Regulation (EC) No 396/2005, which establishes Maximum Residue Levels (MRLs) for active substances in or on agricultural products.⁷ The European Food Safety Authority (EFSA) periodically evaluates these limits based on toxicological data to ensure that long-term and short-term exposures remain below the Acceptable Daily Intake (ADI) and Acute Reference Dose (ARfD).⁸ Monitoring and control activities are implemented through coordinated EU programmes, while non-compliances are reported by the Rapid Alert System for Food and Feed (RASFF). In 2023, pesticide residues represented one of the most frequently reported hazards in EU food products.⁹

Among the fungicides used in strawberry cultivation, pyraclostrobin and boscalid are frequently applied due to their high efficacy and complementary mechanisms of action. Pyraclostrobin, a strobilurin fungicide, inhibits mitochondrial respiration by blocking electron transport at the cytochrome *bc₁* complex (Qo site), whereas boscalid, a carboxamide fungicide, acts by inhibiting succinate dehydrogenase, disrupting fungal energy metabolism.^{10,11} Although their combination provides broad-spectrum disease control, their persistence on fruit surfaces may result in measurable residues that must comply with the MRLs set by EU legislation.

Understanding the dissipation kinetics of pesticides under realistic field conditions is essential for determining pre-harvest intervals (PHIs), predicting residue levels at harvest, and ensuring compliance with regulatory standards.¹² Dissipation studies contribute to refining dietary exposure assessments and improving sustainable pesticide management practices.

Therefore, the objective of this study was to investigate the dissipation behaviour of pyraclostrobin and boscalid in strawberries (*Fragaria × ananassa*)

under field conditions representative of the Serbian agroecological region. Particular emphasis was placed on evaluating residue decline during the pre-harvest interval period and comparing the applicability of two chromatographic approaches (GC–MS and HPLC–DAD) for residue determination. The specific aims were to (i) determine the initial and residual concentrations of both fungicides after application, (ii) model their dissipation rates using first-order kinetics, and (iii) compare the final residue levels with the EU MRLs established under Regulation (EC) No 396/2005.

To achieve these goals, pesticide residues were extracted using a modified QuEChERS (Quick, Easy, Cheap, Effective, Rugged, and Safe) procedure and quantified by gas chromatography coupled with mass spectrometry (GC–MS) and high performance liquid chromatography with diode array detector (HPLC–DAD). The results provide new data on the dissipation kinetics of pyraclostrobin and boscalid in strawberries cultivated under Serbian field conditions and contribute to the development of safe pre-harvest intervals and improved food safety management in accordance with EU regulatory standards.

EXPERIMENTAL

Chemicals and reagents

High-purity boscalid and pyraclostrobin ($\geq 99.9\%$; Sigma-Aldrich, Steinheim, Germany) analytical standards were obtained from commercial suppliers. Individual stock solutions of each pesticide were prepared by accurately weighing the standards into 10 mL volumetric flasks and dissolving them in ethanol (Centralchem, s.r.o., Bratislava, Slovakia) to obtain a final concentration of 1 mg mL^{-1} .

Working standard solutions containing both pesticides at concentrations of $20 \text{ ng } \mu\text{L}^{-1}$ were subsequently prepared in acetonitrile (VWR Chemicals, Rosny-sous-Bois, France). All stock and composite solutions were stored in amber glass vials at -18°C until further use to prevent degradation.

Anhydrous magnesium sulphate was purchased from Lach-ner, s.r.o., (Czech Republic). Sodium Chloride was obtained from Centralchem, s.r.o. (Bratislava, Slovakia) and primary secondary amine (PSA) from Agilent Technologies (USA). Every solvent used was pesticide residue grade.

Field experiments

Field experiments were conducted during the 2024 growing season at experimental sites located in the Republic of Serbia: Gospodjinci ($45^\circ 22' \text{N}$, $19^\circ 50' \text{E}$). The location is representative of the temperate continental climate typical for the Vojvodina region, characterized by warm summers and moderate rainfall. The soil type at both sites was classified as chernozem with neutral pH and moderate organic matter content.

The plant protection product used in this study was a commercial formulation containing boscalid ($267 \text{ g a.i. kg}^{-1}$) and pyraclostrobin ($67 \text{ g a.i. kg}^{-1}$) as active ingredients. This fungicide combination is commonly applied for the control of *Botrytis cinerea*, the causative agent of gray mold disease in berry crops. Treatments were applied to strawberry (*Fragaria* $\times$ *ananassa*, cv. *Joly*) plants at the recommended field application rate of 1.5 kg ha^{-1} , following the

manufacturer's instructions. Applications were carried out once during the fruiting stage, corresponding to growth stages BBCH 65–87 (full flowering to full ripening).

Spraying was performed using a standard field sprayer equipped with flat-fan nozzles, under uniform weather conditions (air temperature 20–25 °C, relative humidity 60–70%, wind speed < 2 m/s) to ensure homogeneous deposition. No additional plant protection treatments were applied during the experimental period.

For the residue analysis, representative samples of mature fruits were collected randomly from different parts of the treated field after the spray deposit had dried (0 day) and subsequently at 1, 2, 3, 4, 5, 6 and 7 days post-application. Each sample consisted of approximately 1 kg of fruit, collected in triplicate. Untreated control samples were harvested from adjacent plots and used for method validation and recovery studies. All samples were immediately transported to the laboratory in insulated containers, stored at 4 °C, and processed within 24 hours of collection.

Sample treatment

Approximately 10.0 g of homogenized frozen strawberry sample was accurately weighed into a 50 mL polypropylene centrifuge tube (Bio-Chrom s.r.o., Bratislava, Slovakia). The sample was extracted with 10 mL of acetonitrile by vigorous shaking for 1 min to ensure complete dispersion of the matrix. During method development, three commonly used QuEChERS approaches were evaluated: the original unbuffered method, the AOAC 2007.01 acetate -buffered method, and the EN 15662 citrate-buffered method. The main differences between these procedures lie in the composition of the extraction salt mixtures, particularly the presence of buffering salts (citrate or acetate), which can influence extraction efficiency and analyte stability. In the original unbuffered QuEChERS method (selected for further analysis), a salt mixture consisting of 4 g anhydrous magnesium sulfate (MgSO_4) and 1 g sodium chloride (NaCl) was added to promote phase separation according to the QuEChERS procedure. The tube was immediately shaken by hand for 1 min and then centrifuged at 4,000 rpm for 5 min. For comparison, the EN 15662 method employs a citrate-buffered salt mixture (MgSO_4 , NaCl , trisodium citrate dihydrate, and disodium hydrogen citrate sesquihydrate), while the AOAC method uses an acetate buffer (MgSO_4 and sodium acetate). All three procedures were tested under identical conditions using spiked samples, and no statistically significant differences in recoveries were observed ($p=0.06$).

Following extraction, an aliquot (typically 5 mL) of the upper acetonitrile layer was transferred into a 15 mL polypropylene centrifuge tube (Bio-Chrom s.r.o., Bratislava, Slovakia) containing 25 mg of primary secondary amine (PSA) sorbent and 150 mg of anhydrous MgSO_4 per millilitre of extract for dispersive solid-phase cleanup (dsPE). The mixture was vortexed for 1 min to facilitate adsorption of polar matrix components and centrifuged again at 4,000 rpm for 5 min.

The resulting supernatant was collected into an amber glass vial prior to chromatographic analysis.

Instrument and apparatus

Analytical weighing of standards was performed using a microbalance Sartorius MC 210 P (Sartorius, Göttingen, Germany). Routine weighing procedures in the laboratory were carried out on an Ohaus Navigator N-34120 balance (Ohaus Corporation, Parsippany, NJ, USA). During sample preparation, a vortex mixer Heidolph Reax (Heidolph, Kelheim, Germany) and a centrifuge Hettich ROTOFIX 32 A (Hettich, Tuttlingen, Germany) were employed. Sorbent materials were activated and dried in a muffle furnace LMH (LMH, Hrušovany u Brna, Czech

Republic), while laboratory glassware was dried in a Binder drying oven (Binder GmbH, Tuttlingen, Germany).

Gas chromatographic analyses were conducted on an Agilent 8890 gas chromatograph (Agilent Technologies, Little Falls, DE, USA) coupled to a 5977C mass spectrometer. The chromatograph was equipped with a multimode inlet (MMI) operated in solvent-vent mode. Separation was achieved on two identical HP-5MS UI capillary columns (15 m $\times$ 0.25 mm i.d., 0.25 μ m film thickness; 5% diphenyl / 95% dimethylpolysiloxane stationary phase). The carrier gas was helium (purity 5.0; Linde Technoplyn, Bratislava, Slovakia). The column flow rate was maintained at 1.2 mL min⁻¹ for column #1 and 1.4 mL min⁻¹ for column #2. A mid-column backflush configuration was applied; during the backflush cycle, the flow in column #1 was reversed to 1.0 mL min⁻¹, while the flow in column #2 remained constant. A 1 m $\times$ 0.32 mm i.d. deactivated fused-silica retention gap was installed between the injector and the analytical column.

The mass spectrometer operated in electron ionization (EI) mode at 70 eV with an ion source temperature of 230 °C and a quadrupole temperature of 150 °C. A single quadrupole analyzer was used for acquisition in both full-scan mode (m/z 50–550) and selected ion monitoring (SIM) mode for quantitative analysis. The ion source was cleaned in situ using the JetClean hydrogen-based cleaning system to minimize contamination and ensure consistent sensitivity.

A liquid chromatograph HPLC-DAD (Agilent Technologies 1100 Series) was applied using a Zorbax Eclipse C18 Reversed-Phase HPLC Column with parameters (50 mm $\times$ 4.6 mm $\times$ 1.8 μ m) and mobile phase was ACN/2.8 pH H₃PO₄ (25: 75 V/V) at a flow rate of 0.55 mL min⁻¹. Injected volume was 20 μ L. The DAD was working at the detection wavelength of 254 nm for both analytes.

Validation experiments

Pesticide-free strawberries were used as the blank matrix for recovery experiments and for the preparation of matrix-matched calibration standards. The absence of boscalid and pyraclostrobin residues in the blank samples was confirmed prior to use by gas chromatographic-mass spectrometric (GC-MS) analysis under the same instrumental conditions as applied for the test samples.

For recovery and validation studies, homogenized blank strawberry samples were spiked with appropriate volumes of working standard solutions of boscalid and pyraclostrobin to achieve the desired fortification levels (three concentration levels: 0.01, 0.05, and 0.1 mg kg⁻¹). After spiking, the samples were thoroughly mixed and left to equilibrate for 30 minutes at room temperature to allow solvent evaporation and uniform distribution of analytes within the matrix. These samples were then subjected to the extraction and cleanup procedure described above.

Matrix-matched calibration standards were prepared by adding aliquots of the mixed working pesticide solutions to blank strawberry extracts obtained from untreated samples. Calibration solutions were prepared at five concentration levels (10 μ g kg⁻¹ – 1000 μ g kg⁻¹) covering the expected linear range of the method. The calibration curves were constructed by plotting the peak area versus analyte concentration, and linear regression analysis was performed.

The limits of detection (LOD) and quantification (LOQ) were calculated from the calibration curve data using the signal-to-noise approach or the standard deviation of the response (σ) and the slope (S) of the calibration curve, according to the equations $LOD = 3.3\sigma/S$ and $LOQ = 10\sigma/S$.

RESULTS AND DISCUSSION

The developed GC–MS method combined with a QuEChERS extraction procedure was successfully applied for the determination of boscalid and pyraclostrobin residues in strawberry fruits (*Fragaria × ananassa*, cv. *Joly*) following field application. The results obtained demonstrate that the analytical procedure provided reliable quantitative data and enabled the evaluation of the dissipation behavior of both fungicides under field conditions typical of Serbian agroecological zones.

Method validation

The QuEChERS extraction method showed good performance for many types of vegetables and fruits. The method requires a sample moisture content of about 80% or above for maximal pesticide extraction.¹³ To identify the most suitable approach for strawberry samples, three official versions of the QuEChERS method were initially evaluated: the original unbuffered version¹³, the AOAC Official Method 2007.01¹⁴ (Acetate-buffered), and the EN 15662 method¹⁵ (Citrate-buffered).

Each procedure was tested under identical conditions using homogenized strawberry samples spiked with boscalid and pyraclostrobin at three concentration levels. The extraction efficiency was assessed by comparing the recoveries obtained after the cleanup step using PSA/MgSO₄.

The results demonstrated that all three QuEChERS protocols provided satisfactory recoveries for both analytes, generally ranging between 80% and 110%. All three procedures were tested under identical conditions using spiked samples. Statistical comparison of the obtained recoveries was performed using one-way analysis of variance (ANOVA), and no statistically significant differences among the tested QuEChERS procedures were observed ($p = 0.06$). Slightly higher recoveries were observed for pyraclostrobin using the acetate-buffered EN method, while the boscalid recoveries were marginally better with the original unbuffered procedure. Nevertheless, these variations were within the acceptable range defined by current validation guidelines (Figure 1).

Considering the comparable extraction efficiency, simplicity, and lower reagent consumption, the original QuEChERS method was selected for further analyses.

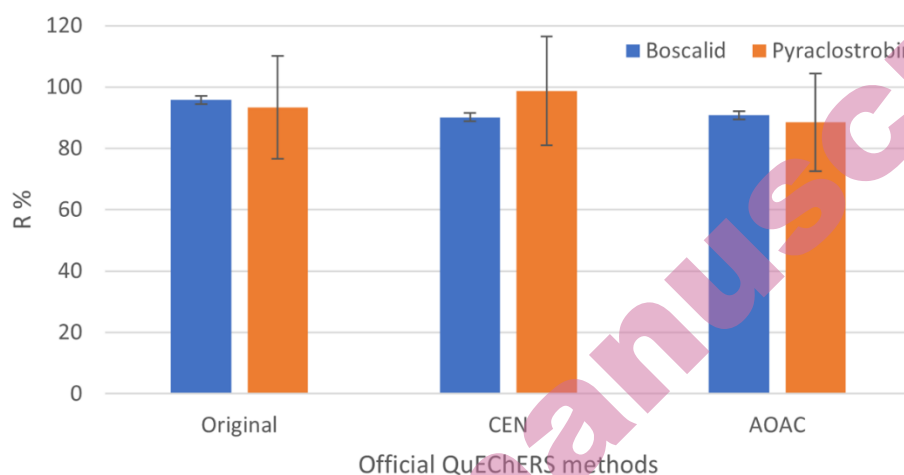


Figure 1. Comparison of recoveries (%) of boscalid and pyraclostrobin from strawberry samples obtained using different QuEChERS extraction methods (original, AOAC 2007.01, and EN 15662) (sample size 10 g, replication $n = 3$, RSD < 20 %)

Recovery experiments performed on blank strawberry samples spiked at three concentration levels (0.01, 0.05, and 0.1 mg kg⁻¹) showed mean recoveries between 84–106%, with relative standard deviations (RSDs) below 10%, demonstrating good accuracy and precision. The use of matrix-matched standards minimized the matrix effect caused by co-extracted pigments, sugars, and organic acids. Extract cleanup using PSA sorbent and MgSO₄ proved effective in removing interfering substances such as lipids and organic acids, yielding clear extracts suitable for GC–MS analysis.

In addition to GC–MS analysis, the HPLC–DAD method was also validated and evaluated for its applicability in routine monitoring of boscalid and pyraclostrobin residues in strawberry samples. The chromatographic method exhibited good linearity across the tested concentration range (10 µg kg⁻¹ – 1000 µg kg⁻¹), with determination coefficients (R^2) of 0.999 for boscalid and 0.977 for pyraclostrobin, confirming the reliability of the detector response.

The method precision, expressed as relative standard deviation (RSD), was 0.47% for boscalid and 6.9% for pyraclostrobin, indicating acceptable repeatability of the retention times and peak areas. The accuracy of the HPLC–DAD method was verified by recovery at three concentration levels (0.01, 0.05, and 0.1 mg kg⁻¹). The mean recoveries ranged from 76% to 92% for boscalid and from 74% to 89% for pyraclostrobin, which are in accordance with the acceptance criteria recommended by the SANTE/113122/2021v2 guidelines.¹⁶

The limits of detection (LOD) were 0.003 mg kg⁻¹ for boscalid and 0.021 mg kg⁻¹ for pyraclostrobin, while the limits of quantification (LOQ) corresponded to

the lowest validated concentration levels that fulfilled precision and accuracy requirements. The LODs obtained in this study are higher than those typically reported for LC–MS/MS methods. This difference is mainly attributable to the use of GC–MS with a single quadrupole detector and HPLC–DAD, which generally provide lower sensitivity than tandem mass spectrometric techniques. Nevertheless, the achieved detection limits were fully adequate for monitoring residue decline under field conditions, where concentrations remained within the mg kg^{-1} range. The matrix effect, evaluated by comparing the slopes of matrix-matched and solvent-based calibration curves, was 89.4% for boscalid and 87.9% for pyraclostrobin, indicating high matrix effects.

These results confirm that both the GC–MS and HPLC–DAD methods provide reliable and complementary analytical performance for the determination of boscalid and pyraclostrobin residues in strawberries. The GC–MS method ensures high sensitivity and selectivity for trace-level confirmation, whereas the HPLC–DAD method offers a cost-effective alternative for routine quantification and method comparison studies.

Dissipation study

The validated method was subsequently applied to determine the dissipation rate of boscalid and pyraclostrobin residues in strawberries following a single field application of a commercial formulation containing 267 g a.i. kg^{-1} boscalid and 67 g a.i. kg^{-1} pyraclostrobin at a dose of 1.5 kg ha^{-1} . Sampling was performed daily over seven consecutive days after application.

At the time of application (day 0), the initial residue levels were 10.23 mg kg^{-1} for boscalid (Figure 2) and 4.23 mg kg^{-1} for pyraclostrobin (Figure 3). Residue concentrations gradually decreased during the following days, reaching 3.01 mg kg^{-1} and 0.39 mg kg^{-1} , respectively, on day 7. The dissipation behavior of both compounds followed first-order kinetics, described by the equation $C = C_0 e^{-kt}$, where C is the pesticide concentration at time t , C_0 is the initial concentration, and k is the first-order dissipation rate constant.

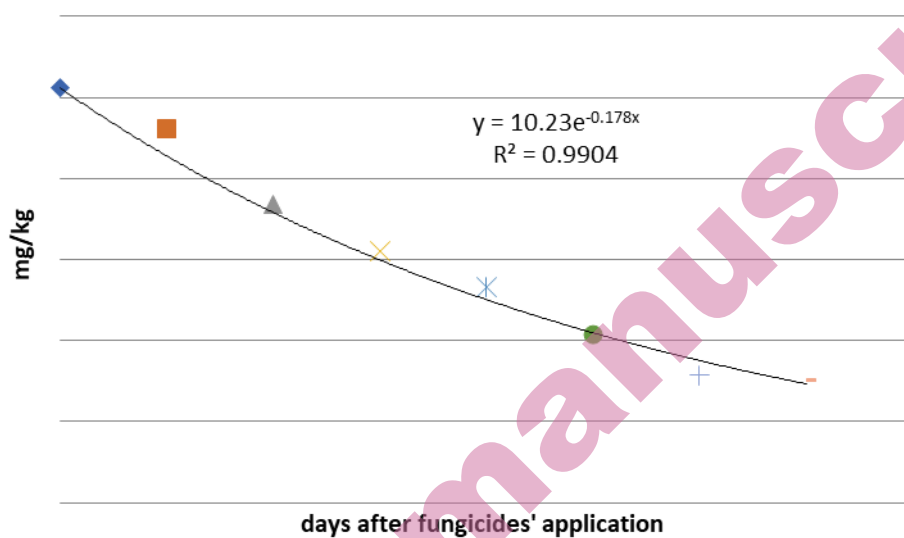


Figure 2. Dissipation kinetics of boscalid in strawberry fruits under field conditions. Residue concentrations (mg kg^{-1}) are shown as a function of time (days) after application. ($n = 3$).

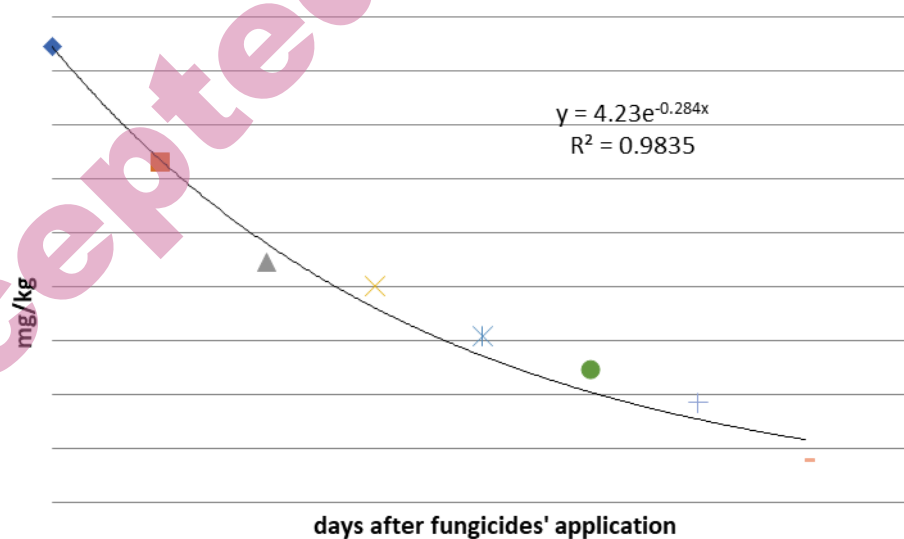


Figure 3. Dissipation kinetics of pyraclostrobin in strawberry fruits under field conditions. Residue concentrations (mg kg^{-1}) are shown as a function of time (days) after application. ($n = 3$).

The calculated rate constants (k) were 0.178 day^{-1} for boscalid and 0.284 day^{-1} for pyraclostrobin, corresponding to half-lives (DT_{50}) of 3.89 and 2.40 days, respectively. The high determination coefficients ($R^2 = 0.9846$ for boscalid and 0.9340 for pyraclostrobin) confirmed an excellent fit of the regression model to the experimental data. Both fungicides exhibited a rapid decrease in concentration during the first three days after application, followed by a slower decline towards the end of the observation period, consistent with a two-phase dissipation pattern typically observed in field conditions.

The dissipation behavior observed for boscalid and pyraclostrobin was influenced by several factors. Variable weather characterized May¹⁷ (RHSS, 2024), with temperatures warmer than the seasonal average and higher than normal precipitation. During the sampling period, the maximum temperature reached 30°C . Morning minimum temperatures were mostly above the multi-year average, ranging from 4 to 18°C . Precipitation was frequent, occurring almost daily, and total rainfall was 125–300% of the long-term average.

Such conditions may have contributed to residue decline through wash-off effects, enhanced plant metabolic activity, and growth dilution in rapidly developing strawberry fruits. The relatively shorter half-life of pyraclostrobin compared to boscalid can be attributed to its higher volatility and greater susceptibility to photodegradation, while boscalid showed slightly higher persistence due to its lower vapor pressure and stronger adsorption to the waxy cuticle of strawberry fruit. These factors may explain the relatively short half-lives observed in the present study.

When compared with previous studies dealing with other pesticides in fruits and vegetables, the DT_{50} values for spinetoram residues in pear fruits were reported by Šunjka *et al.* (2021) and obtained dissipation kinetics for these active ingredients in pears, with half-lives of 2.17 days under comparable climatic conditions.¹⁸ Likewise, dissipation studies of other systemic fungicides, such as imidacloprid and acetamiprid in leafy vegetables, have shown first-order degradation patterns with DT_{50} values between 2.66 – 4.24, depending on the crop and environmental conditions.^{19,20}

These results indicate that the dissipation dynamics of boscalid and pyraclostrobin in strawberries are largely governed by first-order kinetics and are comparable to those of other moderately persistent systemic pesticides. The correlation between time and residue amount was strongly negative ($r < -0.9$ for both compounds), demonstrating consistent exponential decay. The pre-harvest intervals (PHIs) estimated from the regression parameters under the specific experimental conditions of this study were 4.8 days for boscalid and 2.7 days for pyraclostrobin, both shorter than the label recommendation of seven days. These values should be considered indicative estimates based on a single-location and single-season field trial. Data are summarized in Table 1.

Comparable residue concentrations and dissipation curves were obtained using the HPLC–DAD method, with deviations below 10% from GC–MS results. This consistency across analytical techniques further supports the robustness of the obtained data and confirms the reliability of the kinetic model.

Overall, the dissipation profiles indicate that boscalid and pyraclostrobin residues decline rapidly under field conditions and remain well below the European Union maximum residue limits (MRLs) of 6 mg kg⁻¹ and 1.5 mg kg⁻¹, respectively, by the end of the seven-day PHI. These findings not only confirm the safety of the recommended application regime but also demonstrate that both fungicides exhibit predictable and consistent dissipation behaviour that can be modelled accurately for risk assessment and residue management purposes. Although the present study focused on the dissipation of the parent compounds, it should be noted that pesticide degradation may lead to the formation of metabolites or transformation products. The investigation of these compounds, some of which may exhibit different toxicological properties, represents an important subject for future studies employing high-resolution or tandem mass spectrometric techniques.

Although the monitoring period was limited to seven days and residue concentrations remained above the LOQ at the final sampling point, the primary objective of this study was to evaluate residue dissipation during the commercially relevant pre-harvest interval period. Since both fungicides declined below the corresponding EU MRL values within the investigated time frame, the obtained data were considered sufficient for modelling short-term dissipation behaviour under the applied field conditions. Nevertheless, extended monitoring periods may provide additional information regarding the terminal phase of degradation and should be considered in future studies.

Table 1. Dissipation parameters of boscalid and pyraclostrobin residues in strawberry fruits under field conditions based on first-order kinetic modelling. k = first-order dissipation rate constant (day⁻¹); R^2 = coefficient of determination; DT_{50} = half-life (days); PHI = pre-harvest interval (days); MRL = maximum residue limit (mg kg⁻¹). Residue concentrations are given for day 0 and day 7.

Fungicide	Regression equation ($C = C_0 e^{-kt}$)	K /day ⁻¹	R^2	DT_{50} /days	PHI /days*	MRL /mg kg ⁻¹	Residue at day 0 /mg kg ⁻¹	Residue at day 7 /mg kg ⁻¹
Boscalid	$y = 10.23 e^{-0.178x}$	0.178	0.9846	3.89	4.8	6.0	10.23	3.01
Pyraclostrobin	$y = 4.23 e^{-0.284x}$	0.284	0.9340	2.40	2.7	1.5	4.23	0.39

*PHI (pre-harvest interval) calculated based on dissipation curve parameters and MRL thresholds.

Comparison with published data

The dissipation parameters obtained in this study (half-lives of 3.89 days for boscalid and 2.40 days for pyraclostrobin) are in good agreement with previously published results for berry fruits and other fruit crops.

Jankowska *et al.* (2016) investigated the persistence of six pesticides, including boscalid and pyraclostrobin, in tomato samples and reported half-lives of 2.88 and 2.7 days, respectively, confirming their low persistence and first-order kinetic behavior.²¹

In berry fruits, Sadlo *et al.* (2018) studied the dissipation dynamics of boscalid in raspberries grown in Poland and observed a DT₅₀ of 6.8 days ($k = 0.102 \text{ day}^{-1}$, $R^2 = 0.9458$), slightly longer than in strawberries. This difference was attributed to the thicker waxy layer and lower transpiration rate of raspberry fruit surfaces.²² Similarly, Chen and Zhang (2010) examined boscalid dissipation in strawberries at two application rates (349.5 and 525.0 g a.i. ha⁻¹), finding half-lives of 4.9 and 6.4 days, respectively, with first-order kinetics.²³

In pome fruits, Sdeek *et al.* (2023) reported dissipation half-lives of 3.3 days for boscalid and 4.95 days for pyraclostrobin in apples ($k \approx 0.21$ and 0.14 day^{-1} , respectively).²⁴ The longer persistence of pyraclostrobin in apples compared with strawberries is likely related to lower cuticular permeability and thicker epidermal layers in pome fruits.

Comparable dissipation patterns were observed in other crops. Lv *et al.* (2022) reported DT₅₀ values of 3.52 days for boscalid and 3.27 days for pyraclostrobin in watermelon, with residues declining below 0.05 mg/kg after 21 days.²⁵ Under greenhouse conditions, Jankowska *et al.* (2021) found half-lives of 2.01 and 1.62 days for boscalid and pyraclostrobin, respectively, in dill.²⁶ In contrast, higher DT₅₀ values were observed in grapes. Chen *et al.* (2019) compared the dissipation of boscalid and pyraclostrobin in two regions, Beijing and Shandong, reporting boscalid half-lives of 18.8 and 18.1 days, and pyraclostrobin half-lives of 8.9 days, highlighting the influence of regional climatic conditions.²⁷

These results collectively confirm the low persistence and first-order dissipation behavior of both compounds across diverse crops and climates. Overall, the consistency of our findings with previous studies suggests that the dissipation kinetics of boscalid and pyraclostrobin in strawberries are primarily governed by environmental and physicochemical factors rather than crop type or analytical method. Slight variations in DT₅₀ values can be attributed to fruit morphology, wax composition, photolytic degradation, and microbial activity on the fruit surface.

The pre-harvest intervals (PHIs) calculated from our regression models (4.8 days for boscalid and 2.7 days for pyraclostrobin) are consistent with those reported for other berry crops, which generally recommend PHIs of 3–7 days to ensure compliance with EU MRL limits.

CONCLUSION

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ДИНАМИКА ДЕГРАДАЦИЈЕ БОСКАЛИДА И ПИРАКЛОСТРОБИНА У ПЛОДОВИМА ЈАГОДЕ: УТИЦАЈ НА КАРЕНЦУ И УПРАВЉАЊЕ ОСТАЦИМА

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Резултати истраживања су у сагласности са претходним студијама у бобичастом воћу и другим биљним врстама, која истичу утицај услова средине као што су температура, сунчево зрачење и карактеристике покожице плода на динамику разгадње пестицида. Каренце израчунате на основу регресионих једначина износиле су 4,8 дана за боскалид и

2,7 дана за пираклостробин, што је у сагласности са EU MRL вредностима. Добијени резултати потврђују поузданост примењеног аналитичког поступка и пружају значајне податке за рутински мониторинг, процену ризика и одрживу примену пестицида у заштити јагодичастог воћа.

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