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Research Article

# Pesticide Residues in Raisin and Health Risk Assessment

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**Abstract:** This study aimed to determine pesticide residues in raisin samples from the Besni and Gölbaşı districts of Adıyaman province, located in the Southeastern Anatolia region of Türkiye. Method validation was carried out for parameters including linearity, limit of detection (LOD), limit of quantification (LOQ), recovery, precision (repeatability and in-laboratory reproducibility), and measurement uncertainty. The results met the criteria outlined in SANTE/11312/2021. A total of 260 pesticides were analyzed, with pesticide residues detected in 95 out of 100 samples. Among these, 42 samples contained a single pesticide, while 53 samples had two or more residues. The insecticides cypermethrin, indoxacarb, and malathion, along with the fungicides boscalid, flubendiamide, fluopyram, pyrimethanil, and spiroxamine, were identified. All detected pesticide residues were within the LOQ and maximum residue limit (MRL), with no residues exceeding the MRL. According to the analysis, eight different pesticides were identified in the samples. The study confirms that pesticide residues in dried grape samples comply with the MRLs, suggesting minimal health risks for consumers, as both long-term and short-term dietary risks were found to be negligible. However, the presence of multiple pesticide residues underscores the need for ongoing monitoring and stringent regulatory measures to ensure food safety and maintain compliance. These findings provide valuable insights into improving sustainable agricultural practices in grape production and establishing a more effective monitoring system for pesticide residues in raisins.

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## 1. Introduction

Grapes (*Vitis genus*, Vitaceae family) are among the oldest cultivated fruit species, dating back to 3500 B.C. This long history of cultivation has significantly shaped their global economic and cultural importance, particularly in the development of diverse grape-based industries like wine and raisin production. With over 15 000 varieties worldwide, including more than 1 200 in Anatolia, grapes represent significant varietal diversity (Güçer et al., 2021). Approximately 6% of the world's grape cultivation areas are located in Türkiye, the sixth-largest grape producer globally (FAO, 2024). Grape production is important not only for fresh consumption but also for processed products like raisins. Grapes play a significant role in global agriculture, serving as vital raw material for processed products like raisins, which hold considerable economic and nutritional importance.

Türkiye has a prominent role in the global grape industry. Between 2010 and 2021, 51% of Türkiye's total grape production was dedicated to table grapes. According to 2019 statistics, 7% of global grape production was processed into dried grapes. Türkiye ranks first in global raisin exports with a share of approximately 33%. In the 2020/21 season, the leading producers of dried grapes were Türkiye, the United States, Iran, and India, collectively accounting for over 60% of global dried grape production (Demiray and Hatırlı, 2021).

Türkiye holds a significant position as a major producer and exporter of dried grapes worldwide. Most seedless dried grapes are cultivated in the Aegean region. Additionally, viticulture has a longstanding history in Besni, a district of Adıyaman province. The variety known as "Peygamber üzümü" when fresh and the "Besni grape" when dried is predominantly grown in this area and is widely consumed as a dried product (Demiray and Hatırlı, 2021). Raisins are rich in natural sugars and serve as an excellent source of dietary fiber, essential vitamins, minerals, and antioxidants. Raisins are rich in natural sugars, dietary fiber, essential vitamins such as B-complex and K, minerals like potassium, calcium, iron, and antioxidants. The dehydration process concentrates these nutrients, making raisins a healthy and convenient snack. They are also free of fat and cholesterol (Rahimi et al., 2021).

Grape production is challenged by numerous pests and diseases, including insects like *Lobesia botrana*, mites such as *Tetranychus urticae*, and fungi including *Botrytis cinerea* and *Plasmopara viticola*, which require frequent management practices (Balkan and Kara, 2023). Additionally, vineyards are affected by various weed species from different families, necessitating continuous control measure. To produce high-quality, high-yield grapes, producers frequently resort to pesticide applications. These chemicals are preferred to their rapid action, ease of access, and simple application. However, excessive pesticide results in environmental pollution, health risks, resistance development, and residue issues (Polat and Tiryaki, 2022; Duman and Tiryaki, 2023).

The widespread use of pesticides in agriculture has raised significant concerns regarding their potential negative impacts on human health and the environment (Balkan and Yılmaz, 2022). Consequently, monitoring pesticide residues in various matrices, including soil and agricultural products, has become critically important (Cebeci, 2020). This surveillance is essential to understand, control, and regulate pesticide exposure in both agricultural produce and the environment. Such measures play a vital role in protecting consumer health and ensuring the environmental sustainability of agriculture. Monitoring pesticide residues provides a scientific basis for making agricultural practices safer and more sustainable.

In developed countries, the detection and monitoring of pesticide residues is a top priority to safeguard both consumer health and the environment.. The European Union (EU) has implemented the Rapid Alert System for Food and Feed (RASFF), which facilitates swift and coordinated responses to health threats arising from food or feed. Issues related to residues are reported to RASFF contact points and subsequently communicated to the European Commission. This framework enables member states to take necessary precautions or stay informed. In this context, an analysis of RASFF notifications for pesticide residues in grapes an essential export commodity for Türkiye between 2021 and 2024 reveals that active substances such as acetamiprid, cypermethrin, dithiocarbamates, iprodione, lambda-cyhalothrin, metalaxyl, triadimenol, and pyriproxyfen exceeded the Maximum Residue Limits (MRLs) (RASFF, 2024). Additionally, previous studies have reported the presence of various pesticide residues in raisins and grapes, underscoring ongoing food safety concerns (Turgut et al., 2011; Shaber et al., 2017; Nalcı et al., 2018; Yakar, 2018; Constantinou et al., 2021; Mahdavi et al., 2022; Farshidi et al., 2023; Kanbolat et al., 2023; Zhang et al.,2024).

In recent years, consumer sensitivity towards accessing safe food has increased significantly (Nerpagar et al., 2023). The rejection of exported plant-based products at customs due to residue concerns and the resulting negative impact on a country's image have become widely discussed issues. To minimize these challenges, it is essential to disclose agricultural production processes and outcomes transparently. Therefore, on-site residue monitoring across agricultural locations is crucial. Given the rising demand for safe and high-quality agricultural products, the need for systematic residue analysis is more critical than ever. This study aims to analyze pesticide residues in dried grape samples (raisins) and evaluate the potential health risks associated with them.

## 2. Material and Methods

### 2.1. Reagents and chemicals

Pesticide reference materials were purchased from Dr. Ehrenstorfer Laboratories GmbH (Augsburg, Germany). Acetonitrile (MeCN > 99% purity), methanol (MeOH > 99% purity), magnesium sulfate anhydrous ($MgSO_4 \geq 99\%$ purity), ammonium formate ($NH_4HCO_2$ with 99.0% purity) and acetic acid (AcOH) were obtained from Millipore. PSA (Primary Secondary Amine, 40 µm particle size) was supplied from Supelco Analytical (Bellefonte, PA, USA).

### 2.2. Sampling procedure and sample preparation

The collected samples were homogenized, and 7.5 g of each sample was weighed into a 50 ml falcon tube, followed by the addition of 7.5 ml of distilled water. The subsequent steps are illustrated in Figure 1. The extraction and cleanup followed the QuEChERS AOAC Method 2007.01, as outlined by Lehotay, (2007). This method is particularly suitable for this analysis due to its simplicity, efficiency, and effectiveness in handling complex matrices like dried grapes while ensuring high recovery rates for various pesticides.

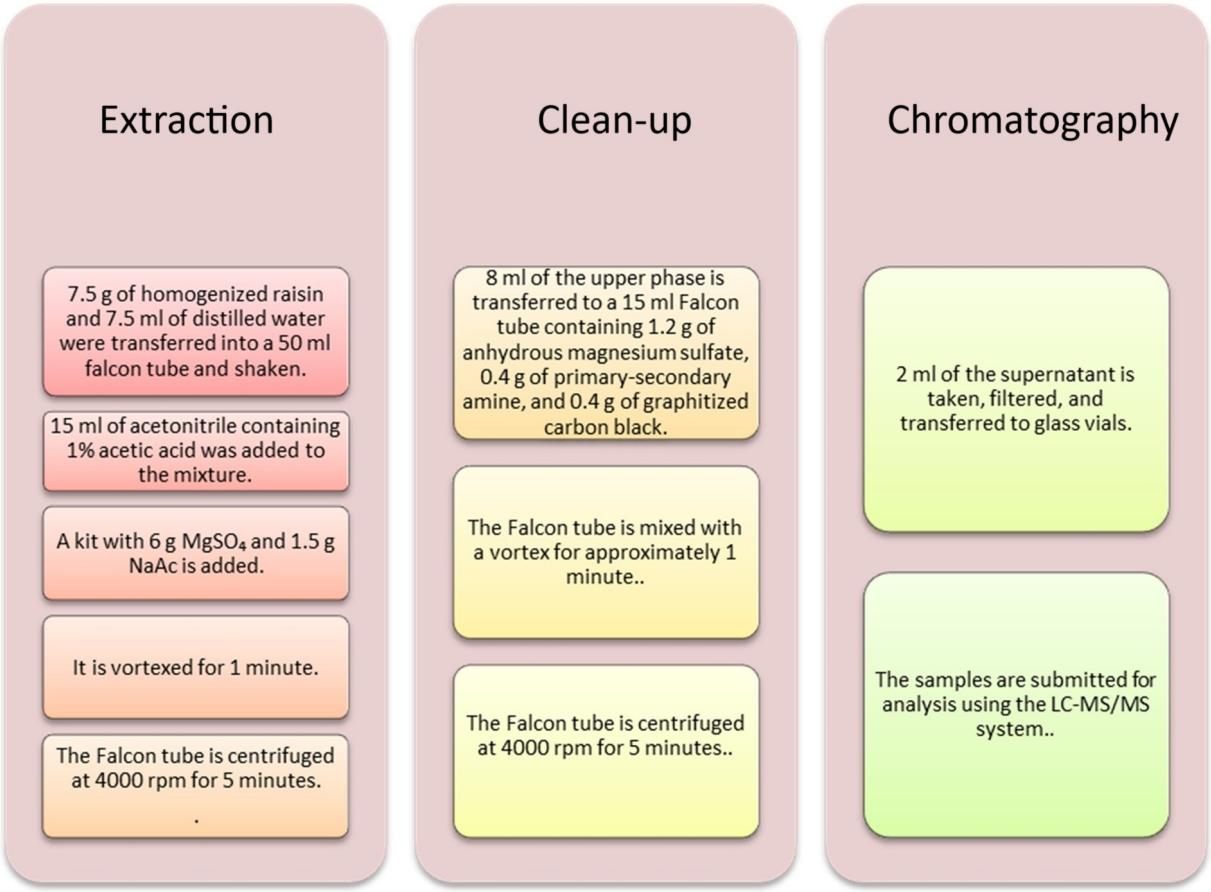


Figure 1. Analytical steps of the QuEChERS-AOAC Official Method 2007.01

## 2.3. Instrumentation and method validation

The analyses were conducted using the equipment and conditions specified in Table 1.

Table 1. Instruments and conditions

| **LC System and Conditions (Nexera X2)** | | **MS Conditions (LCMS-8050)** | |
|---|---|---|---|
| **Pump** | LC-30AD | | |
| **Autosampler** | SIL-20A | **Detector** | MS/MS |
| **Degasser** | DGU-20A3R | | |
| **Column** | Purospher STAR RP-18 endcapped (2.1 mm x 100 mm, 2 µm) | **Ionization mode** | ESI (+/ -) |
| **Oven temp.** | 50 °C | **Desolvation line temp.** | 250 ºC |
| **Solvent A** | 10 mmol $L^{-1}$ ammonium acetate/water | **Interface temp.** | 300 ºC |
| **Solvent B** | Methanol | **Block heater temp.** | 400 ºC |
| **Gradient** | 25%B. (0.5 min)- 98%B. (10.5-13.0 min)-25%B. (13.1-16 min) | **Nebulizer gas flow** | 3.0 L $min^{-1}$ |
| **Flow rate** | 0.4 mL $min^{-1}$ | **Drying gas flow** | 10.0 L $min^{-1}$ |
| **Injection vol.** | 10 µL | **Heating gas flow** | 15.0 L $min^{-1}$ |
| **Rinse solution** | R0: 50% methanol | **Dwell time** | 1-33 msec |

Chromatographic method validation/verification is crucial to quality assurance (QA) and quality control (QC). The QuEChERS method, widely used in well-equipped laboratories requires validation/verification under local laboratory conditions (Dülger and Tiryaki, 2021). Method performance criteria encompass linearity, limits of detection (LOD), limits of quantification (LOQ), accuracy, trueness, precision (repeatability and intra-laboratory reproducibility), and uncertainty. The method has been validated following the guidelines outlined in the "Analytical Quality Control and Method Validation Procedures for Pesticide Residues Analysis in Food and Feed" document (SANTE, 2021).

For the assessment of linearity, a seven-point calibration curve was constructed at concentrations of 0 (blank), 5, 10, 25, 50, 100, and 200 µg $kg^{-1}$, with three replicate injections at each level. Matrix-matched calibration was employed to minimize matrix effects. LOD and LOQ were determined by fortifying a pesticide-free matrix (dried grapes) with a working solution at a concentration of 10 µg $kg^{-1}$. Ten replicate analyses were performed, and the standard deviation (SD) of the results was used to calculate LOD and LOQ. LODs were calculated as three times the SD, while LOQs were defined as ten times the SD, in accordance with established guidelines (Magnusson and Örnemark, 2014). The recovery of pesticides from the matrix and the method's precision were evaluated through five replicate analyses of samples enriched at two different concentration levels (10 and 50 µg $kg^{-1}$). Repeatability (RSDr) was assessed on the same day by two different analysts, whereas intra-laboratory reproducibility (RSDwR) was evaluated over five consecutive weeks, also by two analysts. Precision was expressed as relative standard deviation (RSD), and %RSD values were calculated to ensure compliance with the ≤20% criterion. The accuracy of the data was assessed based on the recovery values obtained from both repeatability and reproducibility studies, ensuring compliance with the acceptable range of 70-120% as defined by (SANTE, 2021). In accordance with SANTE guidelines, the expanded measurement uncertainty (U') for all pesticides was estimated using Approach 2. Instrument data were processed using "LabSolution® software (version 5.97)".

## 2.4. Pesticide residues in raisins

A total of 100 besni raisin samples were analyzed. To detect pesticides of varying chemical structures following extraction and cleanup, a validated QuEChERS-LC-MS/MS method was employed. Three analytical portions were taken from each sample, and all analyses were performed in triplicate. Pesticide identification was based on two key criteria: retention time (RT) and ion ratio in accordance with established guidelines (SANTE, 2021). The detected residues were evaluated against the MRLs set by the European Union (EU-MRL, 2024).

## 2.5. Dietary risk assessment

Dietary pesticide exposure was evaluated by estimating both long-term and short-term intake, corresponding to chronic and acute health risk assessments.

### *2.5.1.Chronic Risk*

The International Estimated Daily Intake (IEDI) (mg $kg^{-1}$ bw) and the chronic exposure risk (HQc) for pesticide residues were calculated using the following equations:

$$\mathrm{IEDI} = (\mathrm{STMR} - \mathrm{P}\ x\ \mathrm{FC})/\mathrm{bw} \quad (1)$$

$$\mathrm{HQc} = \mathrm{IEDI}/\mathrm{ADI} \quad (2)$$

STMR-P (mg $kg^{-1}$) represents the supervised trials median residue (The median residue in raisins was calculated by multiplying the STMR in the raw commodity by a processing factor). FC (kg $day^{-1}$) denotes the average fruit consumption, bw (kg) refers to the average body weight, and ADI (mg $kg^{-1}$ bw) represents the acceptable daily intake of pesticide. The ADI values for the pesticides analyzed were obtained from the EU Pesticides Database (EU-MRL, 2024). The average annual grape consumption per individual was 26.1 kg, corresponding to a daily intake of 0.072 kg for the general national population (TUIK, 2024). A body weight of 73.7 kg was assumed for adults (> 15 years) (TUIK, 2025).

### *2.5.2. Acute Risk*

The assessment of pesticide residue exposure was conducted using a deterministic approach. Short-term intake calculations were carried out based on the International Estimation of Short-Term Intake (IESTI) methodology, as outlined by the Joint FAO/WHO Meeting on Pesticide Residues (FAO/WHO, 2018). IESTI (mg $kg^{-1}$ bw) and acute exposure risk (HQa) were determined using the following equations:

$$\mathrm{IESTI} = (\mathrm{LP}\ x\ \mathrm{STMR} - \mathrm{P}\ )/\mathrm{bw} \quad (3)$$

$$\mathrm{HQa} = \mathrm{IESTI}/\mathrm{ARfD} \quad (4)$$

LP (kg) is the large portion of raisin consumption, ARfD (mg $kg^{-1}$ bw) is the acute reference dose.

If HQ > 1, health risk was deemed unacceptable, while HQ < 1 indicated an acceptable health risk. The large portion consumption values (LP) were sourced from the WHO Food Consumption Database (WHO, 2024). The ARfD (acute reference dose) values for each pesticide were retrieved from WHO and EFSA databases (EU-MRL, 2024). The acute risk of boscalid could not be evaluated due to the unavailability of ARfD.

## 3. Results

### 3.1. Method validation

The method validation parameters for the pesticide in raisins are detailed in Table 2. The correlation coefficients ($R^2$) for the pesticide calibrations exceeded 0.9949. The LOD ranged from 0.85 to 2.65, while the LOQ were calculated to be between 2.83 and 8.85. Recovery values within the method's scope ranged from 79.05% to 114.87%, and relative standard deviation (RSD) values varied from 4.40% to 19.94% (Table 2). According to the SANTE guidelines, each active substance must achieve recovery rates between 70% and 120% and RSD values of ≤20% to meet the method performance criteria. The expanded measurement uncertainty (U') values remained below the 50% threshold established by SANTE. The detected pesticides met all these criteria (Table 2).

Table 2. Method validation parameters

| Pesticide | RT (min) | Precursor ion, m $z^{-1}$ | Product ions, m $z^{-1}$ (CE, eV) | Correlation coefficient ($R^2$) | LOD (µg $kg^{-1}$) | LOQ (µg $kg^{-1}$) | Fortification (µg $kg^{-1}$) | Measured (µg $kg^{-1}$) | Recovery[1] (%) | RSD (%) | U (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Boscalid** | 6.797 | 342.90 | 307.00 (-21) | 0.9949 | 2.65 | 8.84 | 10 | 9.48 | 94.83 | 10.20 | 30.17 |
| | | | 140.30 (-19) | | | | 50 | 41.58 | 83.16 | 6.81 | |
| **Cypermethrin** | 8.902 | 433.20 | 190.95 (-15) | 0.9993 | 2.12 | 7.05 | 10 | 8.08 | 80.77 | 4.56 | 30.93 |
| | | | 192.85 (-15) | | | | 50 | 44.75 | 89.51 | 3.62 | |
| **Flubendiamide** | 7.436 | 680.90 | 254.20 (29) | 0.9973 | 2.49 | 8.29 | 10 | 9.69 | 96.89 | 12.44 | 31.64 |
| | | | 272.10 (18) | | | | 50 | 55.07 | 110.15 | 11.60 | |
| **Fluopyram** | 6.060 | 397.00 | 145.00 (-39) | 0.9953 | 1.56 | 5.22 | 10 | 9.94 | 99.37 | 10.63 | 19.23 |
| | | | 173.00 (-19) | | | | 50 | 48.39 | 96.78 | 6.01 | |
| | | | 208.00 (-18) | | | | | | | | |
| **Indoxacarb** | 8.193 | 528.10 | 203.00 (-25) | 0.9927 | 0.94 | 3.12 | 10 | 9.75 | 97.51 | 12.27 | 32.12 |
| | | | 150.10 (-53) | | | | 50 | 57.43 | 114.87 | 9.54 | |
| | | | 218.00 (-30) | | | | | | | | |
| **Malathion** | 7.129 | 331.00 | 127.10 (-23) | 0.9999 | 1.42 | 4.73 | 10 | 8.63 | 86.35 | 12.56 | 30.46 |
| | | | 99.00 (-23) | | | | 50 | 45.57 | 91.14 | 3.89 | |
| **Pyrimethanil** | 7.379 | 200.10 | 107.00 (-23) | 0.9987 | 2.36 | 7.88 | 10 | 7.91 | 79.05 | 8.17 | 28.74 |
| | | | 82.10 (-26) | | | | 50 | 48.35 | 96.69 | 5.42 | |
| **Spiroxamine** | 8.150 | 298.00 | 144.10 (-30) | 0.9997 | 0.85 | 2.83 | 10 | 8.58 | 85.85 | 5.77 | 23.73 |
| | | | 100.20 (-22) | | | | 50 | 46.52 | 93.03 | 4.83 | |

[1]Overall recovery of the method (accuracy of the method,%):93.50 (n = 320, RSD% =3.85).

### 3.2. Pesticide residue analyses in raisin

The results of the pesticide residue analysis conducted on 100 raisin samples are summarized in Table 3. The analysis identified eight pesticides, with residues detected in 95% of the samples. Among these, three insecticides (cypermethrin, indoxacarb, and malathion), while five were fungicides: boscalid, flubendiamide, fluopyram, pyrimethanil, and spiroxamine. Processing factors, which describe the ratio of pesticide residue levels in processed food to those in raw agricultural commodities, account for changes in residue concentrations due to food processing methods such as drying, washing, or cooking (Polat, 2021). After applying the processing factors, all detected residues were found to remain~~ed~~ below the MRLs (Table 3).

Table 3. Pesticide residues (mg $kg^{-1}$) in raisin

| Pesticide | Frequency of detection | Pesticide residue | Processing factor | Number of samples >LOQ and percentage (%) | Number of samples >MRL | MRL[3] (mg $kg^{-1}$) |
|---|---|---|---|---|---|---|
| Boscalid | 19 | 0.013-0.123 | 2.4 [1] | 95 (95) | - | 5 |
| Cypermethrin | 90 | 0.010-0.219 | 3.3 [2] | | - | 0.5 |
| Flubendiamide | 2 | 0.031-0.121 | 0.3 [1] | | - | 2 |
| Fluopyram | 50 | 0.010-0.082 | 2.9 [1] | | - | 2 |
| Indoxacarb | 2 | 0.014-0.016 | 2.7 [1] | | - | 2 |
| Malathion | 1 | 0.012 | - | | | 0.02 |
| Pyrimethanil | 18 | 0.011-0.049 | 3.7 [1] | | - | 5 |
| Spiroxamine | 1 | 0.016 | 4.0 [1] | | - | 0.6 |

[1]Zincke et al., 2022, [2] Dinçay et al., 2017, [3]EU-MRL, 2024.

In the study, pesticide residues were detected in at least one sample of 95 out of 100 dried grape samples. Among these, one pesticide residue was found in 42 samples, while two or more residues were identified in 53 samples. All 200 pesticide residue values were within the range of the LOQ and the MRL. No residue values above the MRL were detected (Figure 2).

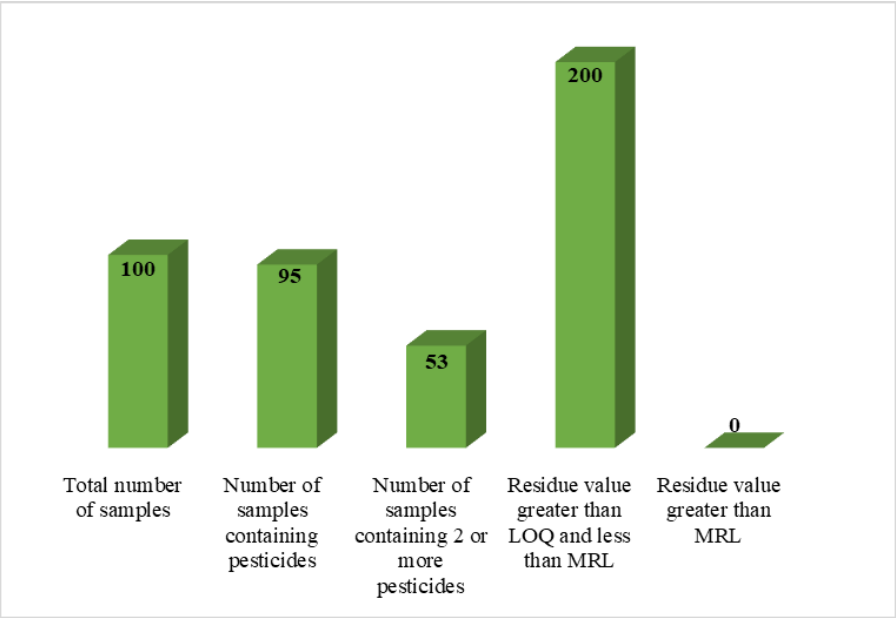


Figure 2. Pesticide residue levels in raisins.

The active ingredients detected in the dried grape samples are presented in Figure 2. Cypermethrin, fluopyram, boscalid, and pyrimethanil were the most frequently identified active substances. According to the Plant Protection Products (PPP) database, cypermethrin is registered at 200 g $L^{-1}$ (preharvest interval, PHI: 7 days) for control of grapevine moth (*Lobesia botrana*); fluopyram is registered at 200 g $L^{-1}$ Fluopyram + 200 g $L^{-1}$ Tebuconazole (PHI: 14 days) for control of powdery mildew (*Erysiphe necator*); boscalid is registered at 200 g $L^{-1}$ boscalid + 100 g $L^{-1}$ kresoxim-methyl, with 50% boscalid (PHI: 28 days) for control of powdery mildew; and pyrimethanil is registered at 300 g $L^{-1}$ pyrimethanil (PHI: 7 days) for control of gray mold (*Botrytis cinerea*) (PPP, 2023).

### 3.3. Health risk assessment

The long-term (chronic) and short-term (acute) dietary risk assessments for the pesticide residues detected in raisins are summarized in Table 4. Chronic dietary exposure was evaluated based on the ADI, while acute dietary exposure was assessed using the ARfD.

Table 4. Long-term and short-term risk assessment of pesticide residues in raisins

| Pesticide | ADI (mg $kg^{-1}$ bw) | Long-term risk assessment IEDI (mg $kg^{-1}$ bw) | HQc | ARfD* (mg $kg^{-1}$ bw) | Short-term risk assessment IESTI (mg $kg^{-1}$ bw) | HQa |
|---|---|---|---|---|---|---|
| Boscalid | 0.040 | 4.60E-05 | 1.15E-01 | / | 2.42E-05 | - |
| Cypermethrin | 0.050 | 5.82E-05 | 1.16E-01 | 0.20 | 2.23E-05 | 1.11E-04 |
| Flubendiamide | 0.017 | 7.37E-05 | 4.34E-01 | 0.10 | 3.10E-04 | 3.10E-03 |
| Fluopyram | 0.012 | 4.15E-05 | 3.46E-01 | 0.50 | 1.81E-05 | 3.62E-05 |
| Indoxacarb | 0.005 | 1.46E-05 | 2.91E-01 | 0.01 | 6.81E-06 | 1.36E-03 |
| Malathion | 0.030 | 1.16E-05 | 3.88E-02 | 0.30 | 1.47E-05 | 4.90E-05 |
| Pyrimethanil | 0.170 | 1.46E-05 | 8.56E-03 | 1.00 | 4.97E-06 | 4.97E-06 |
| Spiroxamine | 0.025 | 1.55E-05 | 6.21E-02 | 0.10 | 4.90E-06 | 4.90E-05 |

The highest HQc value is 0.35 for fluopyram, indicating that its long-term exposure is closest to the ADI but still within acceptable limits. Other pesticides have HQc values significantly below 1, suggesting no considerable long-term dietary risk. The highest acute intake estimate is for flubendiamide (0.003 mg $kg^{-1}$ bw), which remains well below its ARfD (0.10 mg $kg^{-1}$ bw). Indoxacarb (0.001 mg $kg^{-1}$ bw) also shows a notable value but remains within safe limits. All HQa values are below 1, meaning none of the pesticides pose an acute dietary risk. The estimated daily intake for all pesticides is substantially lower than their respective ADI values, indicating no chronic risk. Similarly, IESTI values are well below the ARfD thresholds, confirming that there is no acute dietary risk for consumers.

## 4. Discussion

Pesticide residue studies on dried grapes in Türkiye and other countries indicate similar findings, particularly in detecting pesticides like boscalid, cypermethrin, and pyrimethanil.

Research on pesticide residues in raisins and grapes from Türkiye has revealed significant findings. Turgut et al. (2010) conducted a study on dried grapes from the Aegean region, identifying chlorpyrifos-ethyl, chlorpyrifos-methyl, deltamethrin, lambda-cyhalothrin, dichlofluanid, iprodione, and procymidone. Gazioğlu Şensoy et al. (2017) reported the presence of ten different pesticides in dried grape samples; however, the absence of national or international standard tolerance values for raisins prevented a comparative evaluation of their impact. Dinçay et al. (2017) identified boscalid, cypermethrin, fluopyram, indoxacarb, and pyrimethanil in dried grapes. In both studies from the Aegean region, lambda-cyhalothrin, chlorpyrifos ethyl, and methyl were reported to be above the MRL. The researchers indicated that pyrimethanil exceeded the MRL in dried grapes. Soydan et al. (2021) analyzed 3044 fruit and vegetable samples from the Aegean region, detecting 64 different pesticide residues, including chlorpyrifos, azoxystrobin, triadimenol, carbendazim, pyrimethanil, cyprodinil, fludioxonil, and boscalid, with 11.6% exceeding MRL limits. In reviewing previous pesticide residue studies on raisins and grapes in Türkiye, similar detections of boscalid, cypermethrin, and pyrimethanil were detected. Moreover, while some pesticides were reported to exceed the MRL in earlier studies, no such values were found in our study. The residue levels detected in the Adıyaman province were below the MRL, which may be attributed to the application of cypermethrin during the early stages of fruit development, both before and after flowering, and the early application of pyrimethanil. Agricultural practices in this area, such as the strategic timing of pesticide applications during the early growth stages and the relatively dry climate, which redeuces fungal pressure, play a significant role in maintaining low residue levels contrast, the higher humidity levels in the Aegean region lead to an increased frequency of pesticide applications. Nalcı et al. (2024) reported that pesticide residue levels in early, mid, and late-season grape varieties varied significantly based on agricultural practices and environmental conditions.

When examining pesticide residue studies conducted in other countries, several pesticides including pyrimethanil, cypermethrin, boscalid, and chlorpyrifos have been frequently detected. Constantinou et al. (2021), identified pyrimethanil, boscalid, cyprodinil, fludioxonil, tebuconazole, indoxacarb, fenhexamid, and imidacloprid in dried grape samples, noting that ten of these pesticides are not authorized in the EU. They reported that six pesticides (carbendazim, ethion, fenpropathrin, fenvalerate, iprodione, and phosmet) exceeded the maximum residue limits. Mahdavi et al. (2022) investigated ready-to-eat raisins from Iran, detecting 57 pesticide residues, including carbendazim, acetamiprid, thiodicarb, iprodione, and chlorpyrifos, with 23% of samples exceeding MRLs. Farshidi et al. (2023) recorded residues of azoxystrobin, bromopropylate, chlorpyrifos, cypermethrin, diazinon, difenoconazole, ethion, fenitrothion, fenpropathrin, fenvalerate, kresoxim-methyl, malathion, metalaxyl, penconazole, permethrin, phosalone, and piperonyl butoxide in dried grape samples. Zhang et al. (2024) conducted an extensive four-year analysis in South and Southwest China, identifying 40 different pesticide residues, including difenoconazole, cyhalothrin, and propiconazole, in 94.6% of grape samples, of which 5.7% exceeded MRLs. Compared with studies conducted in other countries, our study found similar active ingredients (boscalid, cypermethrin, indoxacarb, and pyrimethanil) present in the dried grape samples. Studies in Iran and Greece have also reported these compounds in dried grape samples, aligning with the current study's and highlighting common pesticide usage patterns across major grape-producing regions. Pesticide residues in dried grapes are a widespread issue across in various regions, with similar pesticide usage trends observed in multiple studies. The lower residue levels detected in our study suggest that regional agricultural practices and climatic conditions play a significant role in the dissipation of pesticide residues.

## Conclusion

In this study, it was determined that raisin samples contained pesticide residues below the MRLs. The dietary risk assessment confirms that pesticide residues in dried grapes do not pose significant health risks, as all chronic HQc and acute HQa exposure values are below 1. Additionally, the IEDI values are significantly lower than the ADI and the IESTI values remain well below the ARfD. These findings have important implications for both domestic and international trade, as compliance

with MRLs can improve market access and strengthen consumer confidence in the safety of agricultural products. Routine monitoring and strict regulations are essential to ensuring food safety. Specific measures, such as increasing the frequency of random sample testing, implementing digital traceability systems for pesticide usage, and conducting farmer education programs on integrated pest management, could significantly improve the effectiveness of these efforts. The findings can also inform sustainable agricultural practices and improve residue monitoring in grape production. By encouraging policy changes that prioritize stricter residue regulations and adopting advanced technologies like precision agriculture tools and real-time residue detection systems, pesticide use can be minimized while maintaining compliance with safety standards.

## Ethical Statement

Ethics committee approval is not required for the study.

## Conflict of Interest

The authors declare that there are no conflicts of interest.

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## Author Contributions

TB and ÖFÖ made significant contributions to the design and execution of the study. KK contributed to conduction of research. TB and ÖFÖ performed the experiments. TB calculated, analysed and interpreted data. TB and KK attented in designing and writing the manuscript. TB gave final confirmation for the submission of revised version. All authors read, approved final manuscript.

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