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DETERMINATION OF MULTI-PESTICIDE RESIDUE PROFILE, MRL COMPLIANCE ANALYSIS, AND CUMULATIVE DIETARY EXPOSURE RISK ASSESSMENT IN CHERRY (**Prunus avium**) PRODUCTION BASINS OF ISPARTA PROVINCE, TÜRKİYE

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ABSTRACT

This study investigates pesticide residue levels and cumulative health risks in sweet cherries (*Prunus avium*) cultivated in three ecologically distinct regions of Isparta (Eğirdir, Uluborlu, and Sav). Thirty samples from the June 2024 harvest were analyzed for over 400 active substances using QuEChERS extraction and LC-MS/MS. Findings revealed that 100% of samples contained at least two residues, with 93.3% harboring more than three. Fifteen pesticides (8 fungicides, 7 insecticides) were identified, averaging 4.7±1.5 pesticides per sample. The highest detection frequencies were recorded for acetamiprid (93.3%), carbendazim/benomyl (76.7%), and spinetoram (43.3%). Maximum Residue Limit (MRL) exceedances were detected for carbendazim and thiophanate-methyl. While total pesticide load showed no significant regional difference (P=0.49), acetamiprid concentrations varied significantly by location (P=0.034). Chronic risk assessment yielded Hazard Index (HI) values for adults (0.106) and children (0.494) were within safe limits. However, acetamiprid posed an unacceptable acute risk for children (%ARfD=287.2).

Key words: Pesticide residue, cherry, *Prunus avium*, QuEChERS, LC-MS/MS, Maximum Residue Limit, cumulative risk assessment

TÜRKİYE'NİN ISPARTA İLİNDEKİ KİRAZ (**Prunus avium**) ÜRETİM HAVZALARINDA ÇOKLU PESTİSİT KALINTI PROFİLİ TESPİTİ, MRL UYGUNLUK ANALİZİ VE KÜMÜLATİF BESİN KAYNAKLI MARUZ KALMA RİSK DEĞERLENDİRMESİ

ÖZ

Bu çalışma, Isparta'nın (Eğirdir, Uluborlu, Sav) farklı ekolojik bölgelerinde yetiştirilen kirazlardaki (*Prunus avium*) pestisit kalıntı düzeylerini ve kümülatif sağlık risklerini incelemektedir. 2024 Haziran hasadından alınan 30 numune, QuEChERS ekstraksiyonu ve LC-MS/MS yöntemiyle 400'den fazla aktif madde için analiz edilmiştir. Bulgular, numunelerin %100'ünün en az iki, %93.3'ünün ise üçten fazla kalıntı içerdiğini göstermiştir. Toplam 15 farklı pestisit (8 fungisit, 7 insektisit) tespit edilmiş; numune başına ortalama 4.7±1.5 kalıntı saptanmıştır. En yüksek frekansa sahip maddeler asetamiprid (%93.3), karbendazim/benomil (%76.7) ve spinetoramdı (%43.3). Karbendazim ve tiofanat-metil için maksimum kalıntı limitleri (MRL) aşılmıştır. Bölgeler arasında toplam pestisit yükü açısından anlamlı bir fark bulunmazken (P=0.49), asetamiprid konsantrasyonu lokasyona göre varyasyon göstermiştir (P=0.034). Kronik risk değerlendirmesinde Tehlike Endeksi (HI) yetişkinler (0.106) ve çocuklar (0.494) için güvenli sınırlardadır. Ancak, asetamipridin çocuklar için kabul edilemez bir akut risk (%ARfD=287.2) oluşturduğu belirlenmiştir.

Anahtar kelimeler: Pestisit kalıntısı, kiraz, *Prunus avium*, QuEChERS, LC-MS/MS, Maksimum Kalıntı Sınırı, kümülatif risk değerlendirmesi

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INTRODUCTION

Cherry (Prunus avium) is a fruit species of global strategic importance for both fresh consumption and industrial processing. Turkey, with approximately 725 thousand tonnes of annual output, supplies over 27% of global cherry production (FAOSTAT, 2026). Isparta province, situated in the Lakes Region, is one of Turkey's foremost fruit production centres, possessing considerable potential for cherry cultivation owing to its unique microclimate and fertile soils (Akın et al., 2021).

High-yield, quality cherry production necessitates effective management of pests and diseases including the European Cherry Fruit Fly (*Rhagoletis cerasi*), Monilia (*brown rot*), and Cherry Leaf Spot (*Blumeriella jaapii*), prompting growers to implement intensive spray programs (Daniel & Grunder, 2012). However, uninformed or excessive pesticide use risks leaving residues exceeding legally permitted limits. Long-term exposure has been linked to neurotoxicity, endocrine disruption, and reproductive health effects (Mnif et al., 2011), while residues exceeding legal limits create serious trade barriers in markets with stringent food safety standards such as the European Union (Handford et al., 2015).

Pesticide persistence and degradation on plant surfaces are influenced by temperature, UV radiation, rainfall, and humidity (Fantke & Juraske, 2013). Orchard altitude indirectly affects these environmental factors, potentially influencing residue levels at harvest and the pest/disease complex requiring control (Arias-Estévez et al., 2008). Comparing residue profiles across zones with different ecological conditions therefore provides valuable insights into regional agricultural practices (Jiang et al., 2023).

Recent years have witnessed significant changes in global pesticide regulation. European Food Safety Authority's (EFSA) fivefold reduction of acetamiprid toxicological reference values in EFSA PPR Panel 2024 (Hernandez-Jerez et al., 2024), the European Union (EU) non-renewal of carbendazim approval, and MRL updates in both EU and Turkish Food Codex regulations in 2025 (Turkish Food Codex 2025), necessitate re-evaluation of producer practices (EFSA et al., 2025). In this dynamic regulatory environment, generating current residue data from production zones is of critical importance (EUR-Lex 2002).

This study aims to comprehensively characterise the pesticide residue status in cherries produced in Eğirdir (918 m), Uluborlu (1100 m), and Sav (1035 m) - three major cherry production zones of Isparta province differing in geographical and climatic characteristics. The specific objectives are: (i) determination of pesticide residue profiles and statistical inter-zone comparison, (ii) assessment of compliance with national Turkish Food Codex (TFC) and international (EU) MRL values (EUR-Lex 2020), (iii) calculation of total benzimidazole equivalents, and (iv) chronic and acute cumulative dietary exposure risk assessment. To our knowledge, this is the first study to simultaneously assess multi-pesticide residue profiles, MRL compliance under the updated 2025 Turkish Food Codex, and cumulative dietary exposure risk - incorporating EFSA's 2024-revised acetamiprid toxicological reference values - in cherry production zones of Isparta province. The multi-zone comparative design across ecologically distinct basins and the integration of the most current regulatory revisions constitute the primary novelties of this work.

MATERIALS AND METHODS

Study Area and Sampling

Samples were collected from three cherry production zones of Isparta province during the June 2024 harvest: Eğirdir (918 m altitude; semi-humid microclimate influenced by Lake Eğirdir), Uluborlu (1100 m; semi-continental climate, highest altitude), and Sav (1035 m; Mediterranean-continental transitional climate). Ten samples of approximately 2 kg each were randomly collected from commercial orchards in each zone, yielding 30 cherry samples in total (Sav: S-1 - S-10; Uluborlu: U-11 - U-20; Eğirdir: E-21 - E-30). Samples were transported to the laboratory under cold chain conditions.

Pesticide Residue Analysis

Pesticide residues were extracted using the QuEChERS (Quick, Easy, Cheap, Effective, Rugged, and Safe) method (Lehotay et al., 2010). Quantitative analysis was performed using Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS) system. The method enabled screening of over 400 pesticide active substances and their metabolites. The analyses were performed using a Thermo Scientific Ultimate 3000 UPLC system with a Thermo Scientific TSQ Fortis detector. Chromatographic evaluations were conducted using Xcalibur software. A Hypersil Gold RP C18 (1.9 µm), 50 × 2.1 mm

UHPLC column was used for chromatographic separation. The column oven temperature was 40°C. The injection volume was 10 µL. The MS/MS capillary temperature was 270°C. The Limit of Quantification (LOQ) was established at 0.01 mg/kg for all analytes. Method validation was performed in accordance with SANTE/11312/2021 guidelines. Mean recovery rates ranged from 70 to 120% at spiking levels of 0.01, 0.05, and 0.1 mg/kg, with relative standard deviations (13.2) below 20%. Intra-day and inter-day precision (18.9%) were within acceptable limits for all analytes, confirming the suitability of the method for regulatory-level residue determination.

Dietary Exposure and Risk Assessment

For chronic risk assessment, Estimated Daily Intake (EDI) (EDI=C × CR / BW) was calculated for each pesticide and divided by the Acceptable Daily Intake (ADI) to obtain the Hazard Quotient (HQ) (HQ=EDI / ADI) (Boon et al., 2008). The sum of all HQ values yielded the Hazard Index (HI=ΣHQi); HI >1 indicates that cumulative exposure exceeds the acceptable threshold. For acute risk assessment, Estimated Short-Term Intake (ESTI) (ESTI=HR × Cons/BW) was calculated and expressed as a percentage of the Acute Reference Dose (ARfD) (%ARfD=(ESTI/ARfD)×100); %ARfD> 100 indicates unacceptable acute risk (Craig et al., 2020). Consumption parameters were based on the Turkish Dietary Guidelines (TÜBER): 0.066 kg for chronic exposure and 0.2 kg for the acute scenario. Body weights of 70 kg (adults) and 15 kg (children) were used.

Total Benzimidazole Residue Calculation

As thiophanate-methyl and benomyl are rapidly metabolized to carbendazim, these compounds were evaluated as total carbendazim equivalents (EUR-Lex 2024). Conversion factors were calculated from molecular weight ratios: thiophanate-methyl → carbendazim=0.558; benomyl → carbendazim=0.658. Total carbendazim equivalent=[Carbendazim]+([Thiophanate-methyl] × 0.558)+([Benomyl] × 0.658).

Statistical Analysis

Data normality was assessed using the Shapiro-Wilk test. As most pesticide concentrations were non-normally distributed, inter-zone comparisons were performed using the non-parametric Kruskal-Wallis H test, with pairwise Mann-Whitney U tests where significant differences were detected. Non-detected values (< LOQ) were treated as zero in statistical and risk assessment analyses. Although substitution with LOQ/2 or LOQ/√2 represents an alternative approach, assignment of zero was selected as a conservative lower-bound estimate consistent with standard practice in pesticide residue risk assessments (Craig et al., 2020). Given that detected residues dominated the risk profile in the present study, this assumption is considered to have negligible impact on overall Hazard Index values. Statistical significance was set at $P<0.05$. Analyses were performed using IBM SPSS Statistics for Windows, Version 25.0.

RESULTS AND DISCUSSION

Overall Pesticide Residue Profile

The results of the pesticide residue analysis of the cherry samples are presented in Table 1. All 30 samples (100%) contained at least two residues, and 28 of these samples (93.3%) contained more than three pesticide residues.

The number of pesticides per sample ranged from 2 to 7 (mean: 4.7±1.5). Fifteen pesticide active substances were identified, comprising 8 fungicides and 7 insecticides. The majority of samples (60%) contained 4-5 pesticides, while only two samples had 2-3 pesticides (Figure 1). The highest pesticide diversity (7 pesticides/sample) was observed in Uluborlu (U-11, U-13, U-14).

Total pesticide burden per sample averaged 0.696 ± 0.595 mg/kg (median: 0.504; range: 0.152-3.231), with a coefficient of variation of 85.5%, indicating high inter-sample heterogeneity. Acetamiprid was the most frequently detected pesticide (93.3%), followed by carbendazim/benomyl (76.7%) and spinetoram (43.3%) (Figure 2). When comparing the detection frequencies of fungicides and insecticides, both groups were represented in a balanced manner; however, among the fungicides, the prevalence of strobilurin (trifloxystrobin) and pyridine-benzamide (fluopyram) groups is noteworthy, indicating the widespread use of modern combination formulations.

Table 1. Results of the pesticide residue analysis of cherry samples (mg/kg)

Sample No	Zone	Detected Pesticides	Acetamipirid	Carbendazim /Benomyl	Cyantraniliprole	Cypermethrin	Cyprodinil	Deltamethrin	Dodine	Floupyram	Novaluron	Pyriproxyfen	Spinetoram	Spirodiclofen	Tau Fluvalinate	Thiophanate Methyl	Trifloxystrobin
MRL (mg/kg)			**1.5**	**LOD**	**6**	**2**	**2**	**0.1**	**LOD**	**2**	**LOD**	**LOD**	**2**	**2**	**0.4**	**0.3**	**3**
S-1	Sav	5	0.042	ND	ND	0.179	ND	0.018	ND	ND	ND	ND	0.066	ND	0.330	ND	ND
S-2	Sav	4	0.176	0.043	ND	ND	ND	0.030	ND	ND	ND	ND	ND	ND	ND	0.556	ND
S-3	Sav	5	0.296	0.021	ND	0.255	ND	0.031	ND	ND	ND	ND	ND	ND	ND	0.507	ND
S-4	Sav	4	0.227	ND	ND	0.069	ND	0.027	ND	ND	ND	ND	ND	ND	ND	0.015	ND
S-5	Sav	5	0.174	ND	ND	ND	0.013	0.049	ND	0.092	ND	ND	ND	ND	ND	ND	0.032
S-6	Sav	4	0.086	ND	0.269	0.059	ND	ND	ND	0.038	ND	ND	ND	ND	ND	ND	ND
S-7	Sav	5	0.015	ND	ND	ND	ND	0.023	ND	0.095	ND	ND	ND	0.049	ND	ND	0.049
S-8	Sav	5	0.071	0.027	ND	0.048	ND	ND	ND	ND	ND	0.011	ND	ND	ND	0.304	ND
S-9	Sav	5	0.100	0.015	ND	0.222	0.015	ND	ND	ND	ND	ND	ND	ND	ND	0.100	ND
S-10	Sav	5	0.097	ND	ND	0.028	ND	ND	ND	0.066	ND	ND	ND	ND	0.069	ND	0.013
U-11	Uluborlu	7	0.183	0.041	ND	ND	ND	0.011	ND	0.068	ND	ND	ND	ND	0.176	0.226	0.020
U-12	Uluborlu	4	0.068	ND	ND	0.107	ND	ND	0.100	ND	ND	ND	ND	ND	0.018	ND	ND
U-13	Uluborlu	7	0.452	ND	ND	0.019	ND	0.042	0.515	0.067	ND	ND	ND	ND	0.323	ND	0.024
U-14	Uluborlu	7	0.228	0.011	ND	0.206	ND	0.034	ND	0.186	ND	ND	ND	ND	ND	0.068	0.070
U-15	Uluborlu	5	0.038	ND	ND	ND	0.066	0.279	ND	0.017	ND	ND	ND	ND	ND	0.019	ND
U-16	Uluborlu	4	1.077	ND	ND	ND	ND	ND	ND	0.423	ND	ND	0.029	ND	ND	ND	0.198
U-17	Uluborlu	5	0.029	0.067	ND	0.417	ND	ND	ND	ND	ND	ND	0.017	ND	ND	0.100	ND
U-18	Uluborlu	4	0.446	ND	ND	ND	ND	ND	ND	0.195	ND	ND	0.049	ND	ND	ND	0.043
U-19	Uluborlu	3	0.073	ND	ND	0.137	ND	ND	ND	ND	ND	ND	ND	ND	0.039	ND	ND
U-20	Uluborlu	4	0.267	ND	ND	ND	ND	0.182	ND	0.197	ND	ND	ND	ND	ND	ND	0.035
E-21	Eğirdir	5	0.045	ND	ND	ND	ND	0.046	ND	0.218	0.156	ND	ND	ND	ND	ND	0.440
E-22	Eğirdir	4	ND	ND	ND	ND	0.025	0.339	ND	ND	ND	ND	ND	ND	ND	0.020	0.053
E-23	Eğirdir	3	ND	0.068	ND	ND	ND	0.011	ND	ND	ND	ND	ND	ND	ND	0.750	ND
E-24	Eğirdir	6	0.069	ND	ND	0.366	ND	0.010	ND	1.258	ND	ND	0.607	ND	ND	ND	0.921
E-25	Eğirdir	6	0.013	0.040	ND	0.042	ND	0.015	ND	0.021	ND	ND	ND	ND	ND	0.293	ND
E-26	Eğirdir	4	0.070	0.036	ND	ND	ND	0.017	ND	ND	ND	ND	ND	ND	ND	0.671	ND
E-27	Eğirdir	2	0.252	ND	ND	ND	ND	0.022	ND	ND	ND	ND	ND	ND	ND	ND	ND
E-28	Eğirdir	5	0.021	ND	ND	0.034	ND	0.034	ND	0.051	ND	ND	ND	ND	ND	ND	0.012
E-29	Eğirdir	5	0.157	ND	ND	ND	ND	0.040	ND	0.228	ND	ND	ND	ND	ND	0.023	0.062

Bold values indicate residue concentrations exceeding the EU Maximum Residue Limit (MRL) for the respective pesticide. ND: Not detected (< LOQ = 0.01 mg/kg); LOD: EU MRL set at the limit of detection (default MRL applies).

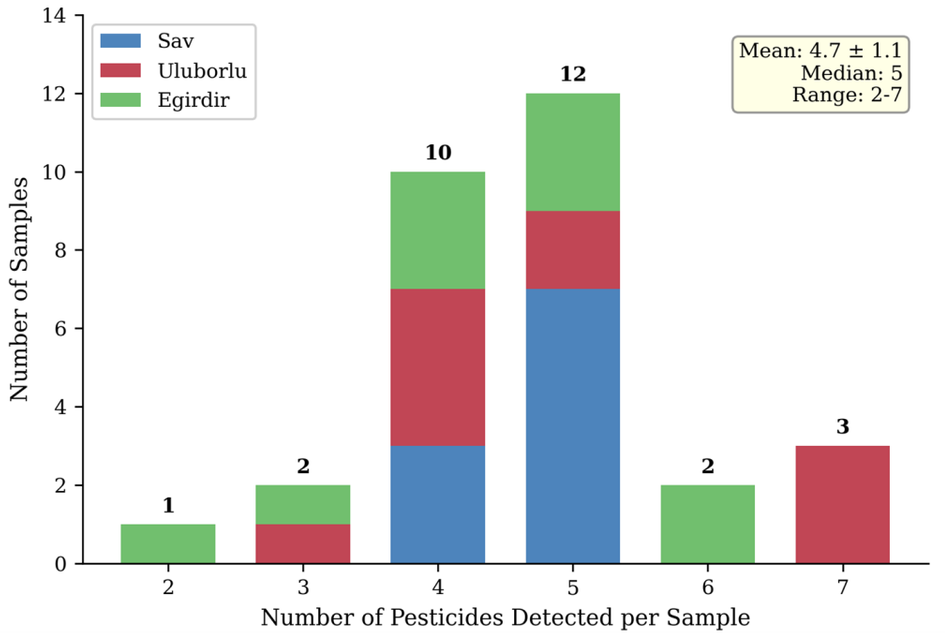

Figure 1. Distribution of the number of pesticides detected per sample (n=30). Colours represent regional distribution: blue - Sav, red - Uluborlu, green - Eğirdir. Mean number of pesticides was 4.7±1.5, with 93.3% of samples harbouring multiple (≥ 2) residues.

Inter-Zone Comparison

Distinct differences were observed among zones in both pesticide diversity and concentration profiles (Table 2). Sav exhibited the highest diversity (13 pesticides), followed by Uluborlu (11) and Eğirdir (10).

Table 2. Total pesticide burden by zone: descriptive statistics and comparison

Zone (altitude)	n	Mean ± SD (mg/kg)	Median	Min.	Max.	CV%
Sav (1035 m)	10	0.512±0.270	0.452	0.231	1.110	52.8
Uluborlu (1100 m)	10	0.770±0.474	0.703	0.249	1.727	61.5
Eğirdir (918 m)	10	0.805±0.886	0.504	0.152	3.231	110.0
Kruskal-Wallis		**H=1.42; *P*=0.49**				

H: Kruskal-Wallis test statistic; P: probability value. A P-value >0.05 indicates no statistically significant difference among zones.
SD: Standard Deviation

Total pesticide burden did not differ significantly among zones (*P*=0.49). As shown in Figure 3, all three zones exhibited similar median values; however, Eğirdir displayed the highest variability (CV=110.0%), attributable to outlier sample E-24

(3.231 mg/kg). The high burden of this sample was driven by 1.258 mg/kg fluopyram and 0.921 mg/kg trifloxystrobin alone, likely indicating a combination formulation applied without adequate observance of the pre-harvest interval.

Among individual pesticides, only acetamiprid concentrations differed significantly among zones (H=6.743; *P*=0.034). Pairwise comparisons revealed significantly higher acetamiprid levels in Uluborlu (mean: 0.286±0.325 mg/kg) and Sav (0.128±0.064 mg/kg) compared with Eğirdir (0.067±0.069 mg/kg; *P*=0.026 and *P*=0.049, respectively). This inter-zone difference is clearly visualised in Figure 4; the non-detection of acetamiprid in two Eğirdir samples contributed to the lower median in that zone. Dominant pesticide profiles were zone-specific: thiophanate-methyl (50%) and cypermethrin (70%) in Sav; fluopyram (70%) and trifloxystrobin (60%) in Uluborlu; deltamethrin (100%) in Eğirdir.

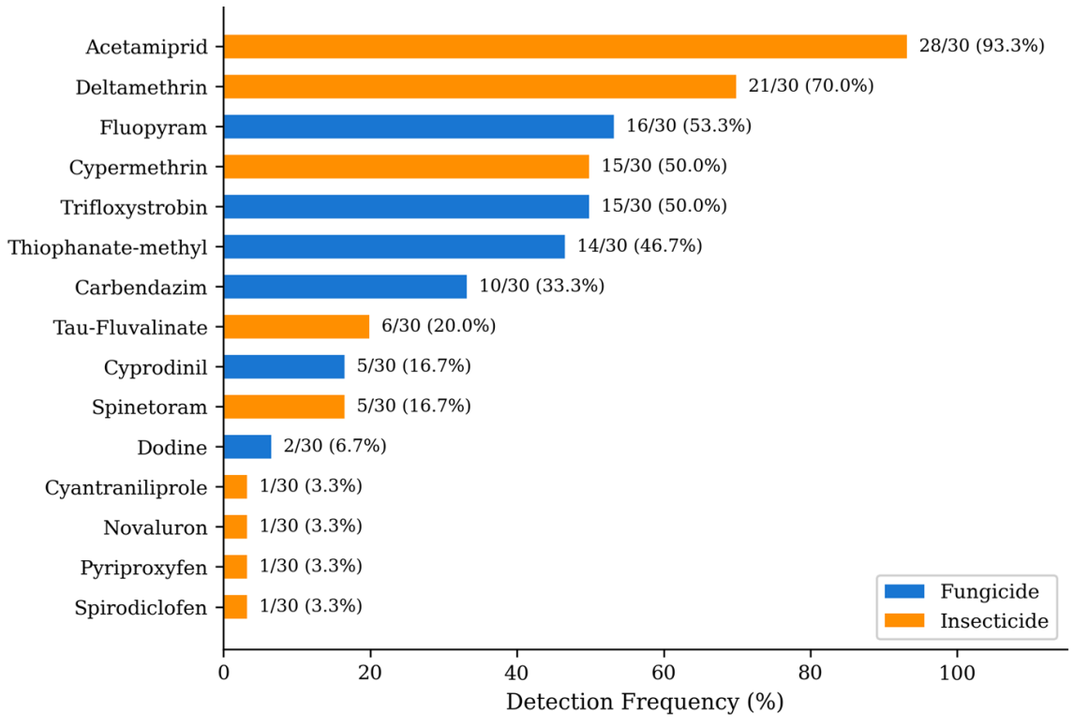

Figure 2. Detection frequencies of pesticide residues in cherry samples (n=30). Blue bars represent fungicides and orange bars represent insecticides. Detection count and percentage are displayed for each pesticide.

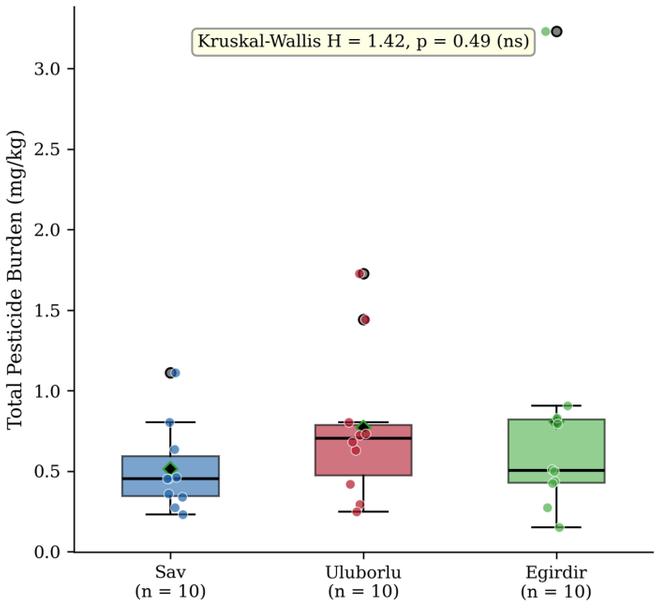

Figure 3. Box plot of total pesticide burden by production zone. Horizontal lines within boxes represent medians, diamond markers represent means, and individual points represent each sample value. Inter-zone differences were not statistically significant (Kruskal-Wallis H=1.42; *P*=0.49).

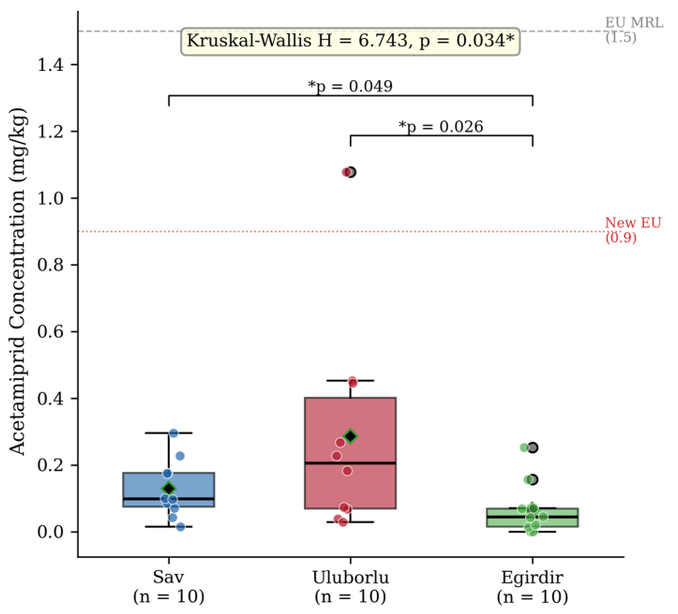

Figure 4. Regional distribution of acetamiprid residue concentrations. Inter-zone differences were statistically significant (Kruskal-Wallis H=6.743; *P*=0.034). Pairwise comparisons (Mann-Whitney U test) with significant differences are shown in brackets. Dashed lines represent the current (1.5 mg/kg) and new (0.8 mg/kg) EU MRL values.

MRL Compliance

Comparison with TFC and EU MRL values revealed exceedances for four pesticides at varying levels (Table 3). Notably, the expiration of carbendazim's EU approval, which reduced the default MRL to the LOQ level (0.01 mg/kg) (FAO 2005), rendered all positive samples non-compliant. The MRL compliance status of all detected pesticides is presented comparatively in Figure 5.

MRL exceedances were distributed across zones: thiophanate-methyl in Sav (S-2, S-3, S-8) and Eğirdir (E-23, E-26); deltamethrin in Uluborlu (U-15, U-20) and Eğirdir (E-22, E-30); acetamiprid in Uluborlu only (U-16). This geographical distribution of exceedances indicates that the problem is not localised to a single zone and supports the need for a basin-wide review of pesticide use practices. Dodine was detected only in Uluborlu (U-12: 0.100; U-13: 0.515 mg/kg). While compliant with the EU MRL (4.0 mg/kg), these values exceed the Eurasian Economic Union (EAEU) default limit (0.01 mg/kg) by 10- and 51.5-fold, respectively. This situation concretely demonstrates that the same residue value can be classified as compliant or non-compliant depending on the target export market.

Table 3. Pesticides with MRL exceedances

Pesticide	EU MRL (mg/kg)	No. exceeded	% exceeded	Max. value (mg/kg)	Max./MRL ratio
Carbendazim*	0.01	10/30	33.3	0.068	6.8×
Thiophanate-methyl	0.30	5/30	16.7	0.750	2.5×
Acetamiprid**	0.80	1/30	3.3	1.077	1.3×
Deltamethrin	0.10	4/30	13.3	0.339	3.4×

* EU approval of carbendazim was not renewed; the default MRL was set at the limit of quantification (LOQ = 0.01 mg/kg). All carbendazim-positive samples therefore exceed the EU MRL regardless of concentration.
** EU MRL for acetamiprid in cherries was revised from 1.5 mg/kg to 0.8 mg/kg following EFSA's 2024 reassessment of toxicological reference values based on developmental neurotoxicity data.
* $P<0.05$ (statistically significant); ** $P<0.01$ (highly statistically significant). ND: Not detected (< LOQ). MRL: Maximum Residue Limit.

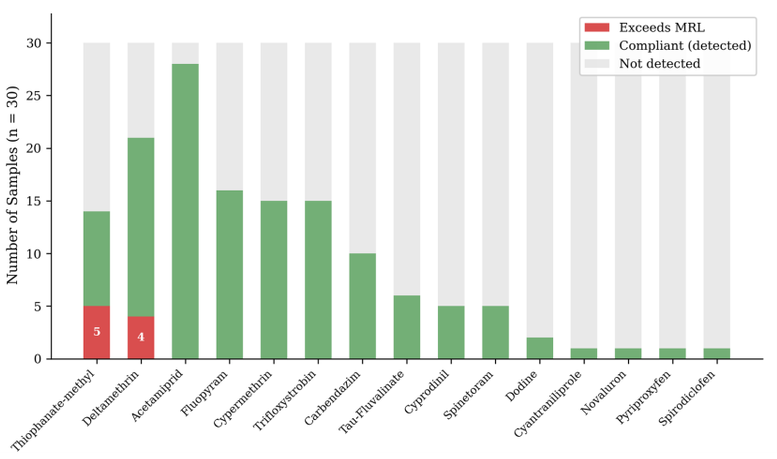

Figure 5. MRL compliance status of detected pesticides (TFC/EU MRL values). Red: number of samples exceeding MRL; green: detected but within MRL limits; grey: not detected (< LOQ). Total n=30.

Total Benzimidazole Equivalents

Total carbendazim equivalents in positive samples ranged from 0.015 to 0.487 mg/kg. The highest value was recorded in sample E-23 (0.487 mg/kg; 48.7 × EU MRL), followed by S-2 (0.353 mg/kg; 35.3 × EU MRL). All positive samples exceeded the EU MRL (0.01 mg/kg). These findings clearly demonstrate that thiophanate-methyl applications constitute the primary source of carbendazim contamination through metabolic conversion.

Chronic Risk Assessment

Cumulative HI values were 0.106 for adults and 0.494 for children, both below the acceptable threshold of 1.0. Children's HI was 4.7-fold higher than adults', a difference driven primarily by the lower body weight (15 kg vs. 70 kg). The three highest contributors to chronic risk were carbendazim/benomyl (HQ children: 0.186), acetamiprid (HQ children: 0.107; updated ADI), and thiophanate-methyl (HQ children: 0.098), collectively accounting for 79% of the children's HI (Figure 6). The combined contribution of the remaining 12 pesticides amounted to only 21%, indicating that risk reduction strategies should prioritize these three active substances.

Acute Risk Assessment

Using current toxicological reference values, no pesticide exceeded %ARfD >100. However, applying EFSA's 2024-revised ARfD for acetamiprid (0.005 mg/kg bw) to the highest residue (1.077 mg/kg, sample U-16) yielded %ARfD=287.2 for children and 61.5 for adults (EFSA, 2016). The five-fold reduction of the acetamiprid ARfD (from 0.025 to 0.005 mg/kg bw) was formally adopted by the EFSA Panel on Plant Protection Products and their Residues in 2024, based on updated developmental neurotoxicity studies (Hernandez-Jerez et al., 2024). The children's value represents 2.9 times the acceptable threshold, indicating unacceptable acute risk. This finding concretely demonstrates that a residue level considered safe prior to the regulatory revision can pose critical risk in light of updated toxicological data.

DISCUSSION

The detection of pesticide residues in all 30 cherry samples and multi-residue contamination in 93.3% of them reveals an intensive chemical crop protection programme in Isparta cherry production. These findings are consistent with EFSA's annual pesticide monitoring reports, which highlight cherries as one of the fruit groups with the highest residue detection rates. Multi-residue detection rates of 100% in sour cherries from Hungary and 85-95% in cherries from Poland have been reported (Lozowicka et al., 2014). The mean of 4.7±1.5 pesticides per sample (Figure 1) indicates that growers in the region are simultaneously combating multiple pests and diseases.

The absence of a statistically significant difference in total pesticide burden among zones (P=0.49; Figure 3) suggests that contamination is not zone-specific but rather a basin-wide systemic issue. Nevertheless, the high coefficient of variation in Eğirdir (CV=110%) reflects heterogeneity in individual grower practices within this zone. The significant inter-zone difference in acetamiprid concentrations (P=0.034; Figure 4), with higher levels in Uluborlu and Sav compared to Eğirdir, points to more intensive neonicotinoid use in these zones, a difference that most likely reflects grower preferences rather than environmental factors. Indeed, the 37-fold variation in acetamiprid concentrations within the same zone (Uluborlu: 0.029-1.077 mg/kg) supports the notion that individual production practices are far more determinative than environmental gradients.

One of the most concerning findings is the detection of carbendazim - whose EU approval has expired - in 76.7% of samples. Carbendazim is an active substance whose approval was not renewed by the EU due to its mutagenic (Category 1B) and reprotoxic properties Carbendazim Substance Regulatory Obligations. (Anonymous, 2026). Concentrations in all positive samples exceeded the EU default MRL (0.01 mg/kg) (Figure 5). Total benzimidazole equivalents reached 0.487 mg/kg (48.7× MRL) in sample E-23. The primary source of this widespread presence is the metabolic conversion of the still-licensed thiophanate-methyl to carbendazim. The concurrent detection of carbendazim in the vast majority of thiophanate-methyl-positive samples strongly supports this scenario. Additionally, the use of banned formulations or root uptake from soil-accumulated residues should be considered as secondary contamination pathways.

The exceedance of the EU MRL for thiophanate-methyl (0.3 mg/kg) in five samples, with the E-23 value of 0.750 mg/

kg reaching 2.5× the MRL, suggests insufficient compliance with pre-harvest intervals (PHI). The TFC amendment of 8 January 2025, which stipulates that limit of detection (LOD) levels (0.01 mg/kg) will apply to pesticides whose authorisation has expired, means that carbendazim-containing products will pose risks not only in export but also in the domestic market. The frequent reporting of carbendazim detections in products of Turkish origin in Rapid Alert System for Food and Feed (RASFF) data demonstrates the tangible trade implications of this risk.

Acetamiprid was identified as the most prevalent pesticide at 93.3% frequency, reaching its highest concentration of 1.077 mg/kg in sample U-16 from Uluborlu (Figure 4). EFSA's five-fold reduction of the ARfD in 2024 based on developmental neurotoxicity evidence and the consequent EU reduction of the cherry MRL from 1.5 to 0.8 mg/kg have fundamentally altered the risk profile for this pesticide. The 1.077 mg/kg value in U-16 exceeds the new EU MRL; more critically, with the updated ARfD, the calculated %ARfD for children was 287.2 - 2.9 times the acceptable threshold. The seasonal nature of cherry consumption with high intake peaks, combined with children's tendency to consume more fruit relative to body weight, amplifies the public health dimension of this acute risk. The non-detection of acetamiprid in two samples from Eğirdir demonstrates that residues can be kept under control on parcels where Good Agricultural Practices are effectively implemented. At the global level, while the EU and Turkey are lowering limits, Codex and Environmental Protection Agency (EPA) maintain 1.5 mg/kg, necessitating that exporters develop target-market-specific residue management strategies. Although the finding that chronic HI values remain below the acceptable threshold (adults: 0.106; children: 0.494) is favourable, the proximity of children's HI to half the threshold and the fact that 79% of total risk originates from only three pesticides (carbendazim, acetamiprid, thiophanate-methyl) are noteworthy (Figure 6). This result indicates that residue-level control of these three active substances should be prioritised for risk reduction. It should be borne in mind that the calculated HI values reflect exposure from cherry consumption alone; in reality, consumers are exposed to the same pesticides through multiple food sources.

The multi-residue presence (93.3% multi-residue rate) also raises the issue of potential synergistic effects among compounds sharing the same mode of action. The benzimidazole group and pyrethroid group detected in this study are compound classes that should be evaluated under the dose-addition principle within EFSA's Cumulative Assessment Groups (CAG). That dodine was detected only in Uluborlu and - while compliant with EU limits - exceeded the EAEU default limit by 51.5-fold constitutes a concrete example of MRL asymmetry across different export markets. Taken together, these findings underscore the urgent need for dissemination of Integrated Pest Management strategies, enforcement of PHI compliance, and pre-dispatch analysis of export lots against target-market criteria in Isparta's cherry sector

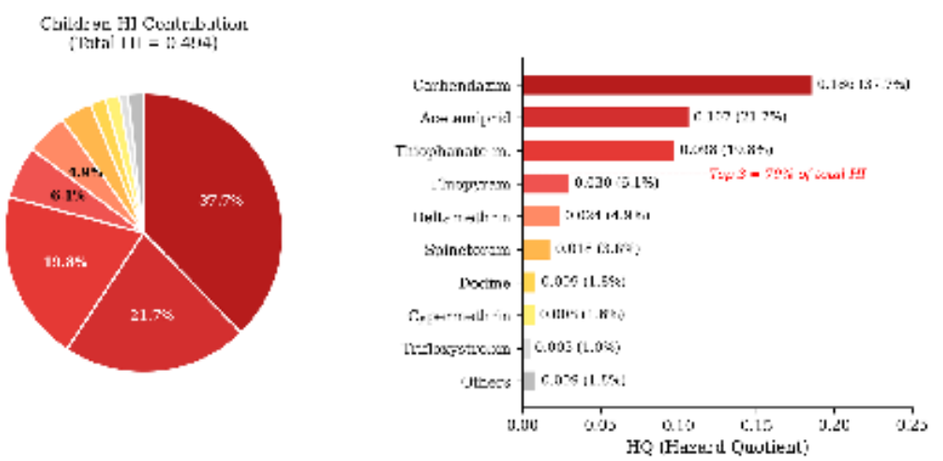

Figure 6. Contribution of individual pesticides to cumulative chronic health risk (HI) for children (1-6 years). Left: pie chart; right: HQ value and percentage for each pesticide. Total HI=0.494. The dashed red line indicates that 79% of total risk originates from only three pesticides (carbendazim, acetamiprid, thiophanate-methyl).

CONCLUSION

This study has demonstrated widespread pesticide contamination (100% detection, 93.3% multi-residue; 15 different pesticides) in cherries produced in the Sav, Uluborlu, and Eğirdir zones of Isparta province. The detection of EU-deauthorised carbendazim at 76.7% frequency and total benzimidazole equivalents reaching 49× the EU MRL constitute the most critical residue problem in the region. The %ARfD of 287.2 calculated for children using EFSA's updated toxicological reference values for acetamiprid signifies an unacceptable level of acute risk. Although chronic cumulative risk remains within acceptable limits, the proximity of children's HI (0.494) to half the threshold and the concentration of 79% of total risk in only three pesticides are concerning (Figure 6).

Total pesticide burden did not differ significantly among zones (P=0.49), indicating that the problem is systemic across the basin. Immediate measures required include monitoring the use of banned formulations, ensuring thiophanate-methyl PHI compliance, and optimising acetamiprid dosages. In the medium term, dissemination of Integrated Pest Management strategies, development of market-specific residue management systems, and regular repetition of regional monitoring programmes are recommended.

AUTHOR CONTRIBUTIONS

Conceptualization: SYK, YÖ, Sİ; Data curation: YÖ, Sİ; Formal analysis: SYK; Funding acquisition: YÖ; Research: SYK, YÖ, Sİ; Methodology: YÖ, Sİ; Project management: YÖ; Resources: YÖ, SYK; Software: SYK, YÖ, Sİ; Supervision: YÖ, SYK; Validation: YÖ, SYK; Visualization: SYK; Writing - original draft: SYK; Writing review & editing: YÖ, SYK.

CONFLICTS OF INTEREST

The authors declare that they have no conflict of interest.

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