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Quantification of pesticide residues in fruits and vegetables sampled in Sicily (Italy) and assessment of health risks

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A R T I C L E I N F O

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A B S T R A C T

This study aimed to assess the presence and concentration of 220 pesticide residues in 475 vegetable samples collected from 90 locations across Sicily, Italy. This paper presents chemometric analyses and risk assessments performed on a large dataset concerning pesticide analyses in Sicilian vegetables. The analysis employed the QuEChERS extraction method followed by gas GC-MS/MS and LC-MS/MS. The analytical protocols demonstrated good sensitivity and selectivity, with determination coefficients (R^2) greater than 0.998 for all analytes. Recovery percentages for different pesticides ranged between 60 % and 140 %, ensuring reliability in quantification. Most pesticides have LOQ values at 0.006 mg Kg^{-1}, confirming method sensitivity. Among the detected residues, Boscalid, Acetamiprid, Deltamethrin, Tebuconazole and Chlorpyrifos were the most frequently found compound in samples. Some samples exceeded the European Union's Maximum Residue Limits (MRLs), raising concerns regarding consumer safety. By comparing the concentrations of the active ingredients in our samples with the maximum values reported by the European Community, all the samples, with the exception of one of peaches and another of prickly pears, whose concentrations of Chlorpyrifos and Etofenprox were above the legal limits, we can conclude that the others comply with European legislation. We can be concluded that the HQ values for all the pesticides studied are below the established threshold of 1 for both adults and children. Consequently, the population exposed to pesticides through fruit and vegetable consumption can be considered safe. Only in the case of boscalid in a blackcurrant sample, the HQ value was slightly higher than 1.

1. Introduction

It is well known that plant based food, particularly fresh fruit and vegetables, play an important role in the human diet by providing essential micro- and macronutrients, which have a positive effect on health, in fact, several World Organizations (World Health, 2005) recommend a consumption of 400 g of these foods (excluding tubers) per day to prevent some chronic diseases (heart disease, cancer, diabetes, obesity, etc.). On the other hand, compared to other foods and beverages, the consumption of vegetables, involves a greater intake of many organic (pesticides, PAHs, etc.) and inorganic pollutants including nitrates (Amorello et al., 2025a,b; Amorello et al., 2022; Amorello et al., 2023).

Since ancient times, humans have tried to control crop pests: the ancient Romans used sulfur as a fumigant, the Chinese used arsenic compounds in their gardens as early as 900 AD. Although some synthetic chemicals were introduced in the 1930s, the modern agrochemical industry developed after World War II. Dithiocarbamates, for example, were discovered in the 1930s and used as fungicides for agricultural applications during World War II (Szolar, 2007). In the 1940s, organochlorine insecticides such as DDT and hormone-like herbicides such as MCPA and 2,4-D were introduced. The agrochemical industry has been in constant development worldwide since 1945, and there are currently around 400 active ingredients registered in the European Union and around 1200 in the USA. Today the global pesticide market was stimmed at $104 billion, with annual consumption exceeding 4.3 million tons across more than 1000 chemical, microbiological, and botanical formulations (FAO, 2024; Malhat et al., 2025).

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Generally, the pesticide formulations are mixtures of active and other substances. Active substances, are chemical compounds that prevents, kills, or repels a pest or acts as a plant regulator, a desiccant, a defoliant, a synergist, or a nitrogen stabilizer. Due to differences in the chemical and physical properties of the active substances, the ability to control parasites and the simplicity of handling, transporting and using them, pesticide formulations are sold in many different products. In addition to the active ingredients, commercial products may contain inert substances that aid application. These inert substances can be solvents, carriers, surfactants or other compounds that are deliberately added. The use of agrochemicals in agriculture has allowed for an increase in both the quality and quantity of agricultural production. On the other hand, however, agrochemicals can contaminate the environment and remain as residues on final products such as fruit, vegetables and cereals. Depending on the dose ingested, this can have negative effects on the health of consumers. Various regulations have therefore been issued over the years regarding agrochemicals and their residues to protect consumer health.

Although several studies exist on various non-European products (Nisha et al., 2021), those regarding the most commonly consumed plant-based foods in Italy are rather limited (Santarelli et al., 2018). Therefore, the aim of this research is to quantify the active ingredients present in trace or ultra-trace levels in fruit and vegetable samples sold in Italy. In detail, this research intended to assess the presence and quantification of more than four hundred pesticide residues in 475 vegetable food samples sold in Sicilian marked.

The analysis was carried out by use of the QuEChERS extraction method combined with liquid chromatography-tandem mass spectrometry (LC-MS/MS) and gas chromatography-tandem mass spectrometry (GC-MS/MS) to warrant high sensitivity and accuracy on the final results.

The *QuEChERS* method (Quick, Easy, Cheap, Effective, Robust and Safe) was originally developed by the USDA in collaboration with EU food regulatory agencies for sample preparation (fruit, vegetables, etc.) for multiresidue pesticide analysis. The method's main advantage is that it reduces the use of expensive and/or hazardous solvents compared to traditional techniques.

The study established the prevalence of pesticide residues in vegetable food samples, evaluating their agreement to the European Union's MRLs, and identifying the most frequently detected active ingredients and their co-occurrence patterns. Also, the distribution of single versus multiple pesticide residues was monitored to understand contamination trends. A health risk assessment was also carried out to assess the potential dietary exposure risks associated with consuming pesticide-contaminated food.

In summary, this paper presents chemometric analyses and risk assessments performed on a large dataset concerning pesticide analyses in Sicilian vegetables.

2. Materials and methods

2.1. Sampling

Fruit and vegetable sampling was carried out during four seasons in 2020/2021, taking care to obtain those consumed during the period. 475 samples of fresh plant foods (fruit, citrus fruits and vegetables) were collected from 90 different Sicilian locations (Fig. 1). All samples were furnished from large retailers (fruit and vegetable markets, food storage and wholesale companies, supermarkets, etc.). After collection, the samples were stored in a freezer at –18 °C until analysis.

2.2. Materials

All chemicals were used as received without any further purification. Methanol for MS analyses 99.95 %, Acetonitrile for HPLC-MS 99.99 %, Formic acid 99 %, Ammonium formate grade analysis 99 % and Water for HPLC were supplied by Carlo Erba Reagents (France). Solid Ethion Certified Reference Material (MRC) and solid Triphenylphosphate (TPP) Certified Reference Material (MRC) were purchased from Sigma Aldrich. Restek Certified Reference Material (MRC) 1–9, Restek Pesticide Mix (GC Multiresidue Pesticide Kit), Restek Certified Reference Material (MRC) 1–10, Restek Pesticide Mix. were purchased from RESTEK. SUPELCO dSPE Citrate Extraction Tube cat. 55227-U (4 g magnesium sulfate + 1 g sodium chloride + 0.5 g sodium citrate dibasic hexahydrate + 1 g sodium citrate tribasic dihydrate) (Merck, 2025) and SUPELCO (Sigma Aldeich, Milano) dSPE PSA SPE Cleanup Tube 1 cat. 55228-U (900 mg magnesium sulfate + 150 mg PSA resin) were used.

2.3. Analytes

The analytes considered in this study are reported in Tables 1–3 of Supplementary Section.

2.4. Calibration

To determine the concentration of each analyte (Tables 1 -3 Supplementary Section), a matrix calibration line was constructed, both for GC-MS/MS and for LC-MS/MS, by preparing 6 solutions, at different concentrations, by diluting the Reference Materials (RM) solutions. The procedure for preparing the calibration solutions for GC-MS/MS is reported in (Table 4 Supplementary Section), that for LC-MS/MS in (Table 5 Supplementary Section),

As examples, some of the calibration lines relating to the analysis by GC-MS/MS are shown in Figs. 1 and 2 of Supplementary Section and those by LC-MS/MS in Figures 3 and 4 of Supplementary section. In all cases, the concentrations of the solutions expressed in μg L^{-1} are shown on the x-axis, while the areas of the chromatographic peaks on the y-axis. For all the compounds considered in this work, the determination coefficients of the calibration lines are greater than 0.998.

2.5. Instrumentation

The quantification of the different compounds was carried out using two types of analytical instruments: a Gas chromatograph with triple quadrupole mass spectrometer, Thermo Scientific TSQ Quantum XLS (Thermo Scientific, FL, USA) to monitoring semi volatile and volatile compounds, equipped with a 30 m x 250 μm x 0.25 μm TR-5MS column (Thermo Scientific, Waltham, MA, USA), and helium was used as carrier gas; a liquid chromatograph with triple quadrupole mass spectrometer Thermo Scientific Quantum TSQ Vantage, (Thermo Scientific, FL, USA) to monitoring non-volatile compound, coupled to an Agilent Eclipse XDB-C18 2.1 × 100 mm column (Agilent Technologies Italia SpA – Milano) and, as mobile phase used consisted of a mixture of H_2O, 2 mM $HCOONH_4$, 0.1 % HCOOH and b) CH_3OH, 2 mM $HCOONH_4$, 0.1 % HCOOH.

2.6. Sample extraction and purification

The sample, after being thawed (taking care to keep it cold at 4 °C), was carefully homogenized using a Buchi B-400 mixer (BUCHI Italia s.r.l, Cornaredo Italia). After that, 10 ± 0.1 g of sample, carefully weighed in a 50 mL disposable centrifuge tube, 100 μL of MRsur3 TPP solution at 1 mg L^{-1} (surrogate standard for GC) and 100 μL of MRsur3 Ethion 1 mg L^{-1} (surrogate standard for LC) were added. The mixture was shaken on a vibromixer (Rütten Engineering Ltd Sterile Storage Systems, Tagelswangen, Switzerland) for about 1 min. Subsequently, 10 mL of acetonitrile were added, shaking on a vibromix for about 1 min and leaving in the freezer for 15 min. After this time, the extracting phase Supelco dSPE Citrate Extraction Tube cat. 55227-U (Sigma-Aldrich, Milano Italy) was added, after shaking on a vibromixer for about 1 min, it was centrifuged at about 3500 rpm for about 5 min. 6 mL of the supernatant were transferred to a disposable tube containing the purification phase Supelco PSA CleanupTube 1 (cat. 55228-U) (Sigma-Aldrich, Milano Italy). The tube was shaken on a vibromixer for 1 min. The sample was then centrifuged at 3500 rpm for 5 min. Subsequently, 1 mL of the centrifuged solution was transferred into a 2 mL vial for LC-MS/MS analysis, and 5 mL to a 10 mL centrifuge tube. The latter was evaporated to dryness in a nitrogen stream at 30°C, to concentrate the sample. The residue was dissolved in 0.5 mL of acetonitrile and transferred into a 2 mL vial for GC-MS/MS analysis.

2.7. Analysis

After sample extraction and purification, active substances quantifications were carried out using GC-MS/MS and LC-MS/MS, both operating in Single Reaction Monitoring (SRM) mode. For LC analyses, 25 µL of an isotopic standard mix solution at 5 µg/L of acetochlor, acetamiprid, cypermethrin and malathion (internal standard for LC) were added to 1 mL of sample. For GC analyses, 25 µL of a dimethoate isotopic standard solution at 50 µg/L (internal standard for GC) was added to 1 mL of sample. Each sample was analyzed three times. The optimal concentration range for the analysis was from 0.005 to 0.04 mg Kg^{-1}. Samples with concentrations higher than the maximum measurement limit were appropriately diluted to 100 times. The compounds identification was performed by comparing both retention times and spectrometer data base on quantification and qualification ions. Instrumental parameters (Retention time, Parent ion, Product ion, Collision energy, etc.) are shown Tables 1–3 of Supplementary Section. Typical chromatograms of the investigated compounds both using GC-MS/MS and LC.MS/MS are reported in Figures 5–12 of Supplementary Section.

2.8. Quality control and method validation

Prior to performing the analyses, the method was validated in accordance with UNI EN ISO 17025:2018 (UNI CEI EN ISO/IEC 17025:2018) and the European SANTE 2016 guidelines (SANTE/11945/2015 Supersedes SANCO/12571/2013 Implemented by 01/01/2016.). The analytical procedure was validated by analysing spiked samples and investigating the following parameters:

- Selectivity was guaranteed using specific SRM transitions and labeled standards, and this was tested by analyses on spiked matrices.
- Linearity was evaluated by calibration curves. Standard solutions at different concentration were analysed and the linearity was considered acceptable when the determination coefficient R^2 was greater than 0.995.
- Accuracy (expressed as percentage recovery) and precision (repeatability, expressed as the relative standard deviation as a percentage) were evaluated by analysing spiked samples at a minimum of three different levels. For all analytes considered, accuracy ranged from 60 % to 140 %. in good accordance with the validation performance reported in the guidelines.
- The limit of quantification (LOQ) was determined as ten times the standard deviation (Sr) of the signal at the first calibration level for each analyte.

To monitor analytical process, blank samples and duplicate matrix spike samples were prepared as discussed below. In detail, to obtain a blank sample, a tomato sample was used in which no type of pesticide was found in preliminary analyses. This blank sample was then used to obtain calibration lines for all samples except for citrus fruits, for which an orange sample, also free of pesticides, was used. The same extraction and purification procedure used for the samples was performed to prepare the matrix blank. The limits of detection (LOD) and quantification (LOQ) were calculated based on blank samples, as described in previous papers (Amorello et al., 2025a; Barreca et al., 2023; Di Gaudio et al., 2023). Quantification limits for every active compound and measurement range obtained on a tomato sample are shown in Tables 6 and 7 of Supplementary Section.

During the analyses, some quality control parameters reported below were checked:

- efficiency and proper functioning of the instrumentation;
- retention time for the Aldrin target ion;
- concentration of the calibration standard (STD 0.010 mg L^{-1}) verifying that it did not differ by ± 20 % from the expected value;

To evaluate the precision of the analysis, three replicates of the same sample were analyzed. The relative standard deviations of the replicates on the concentrations of individual compounds ranged from 4 % to 30 % and are satisfactory for determinations at the µg kg^{-1} level. As in other paper (Habib, 2021), to establish the recovery percentages, spiked samples were prepared by us starting from matrix blank, prepared as previously mentioned, adding 100 µL of the Mrmix solution at 1 mg L^{-1} and 100 µL of MRsur3 TPP solution at 1 mg L^{-1}, for GC-MS/MS analysis, while for LC-MS/MS analysis, adding 100 µL of Mrmix1* solution at a concentration of 1 mg L^{-1} and 100 µL of MRsur3 Ethion solution at 1 mg L^{-1}. Validation data obtained on a tomato sample, fortified at LOQ and at the double LOQ are shown in Tables 8 and 9 of Supplementary Section.

2.9. Health risk assessment

As in other cases (Bhandari et al., 2019; Rahman et al., 2021), we chose to evaluate dietary risks from pesticide consume for the population groups adopted by the WHO (WHO, 2013): children (0–14 years), adolescents (10–19 years) and adults (>19 years). Individual body weight adopted from the international standards of the WHO (2011) were 10 Kg for children, 32 Kg for adolescents and 62 Kg for adults.

The dietary exposure to the investigated pesticides, as in other papers (Malhat et al., 2025) was assessed to evaluate the long-term health risks for adults in Sicily. As in other paper (Valcke et al., 2017), the estimated daily intake (EDI, mg Kg^{-1} day^{-1}) was calculated by multiplying the average residual pesticide concentration (mg Kg^{-1}) by the food consumption rate (Kg day^{-1}) and dividing by the consumer's body weight 62 Kg for an adult, 32 for an adolescent and 10 Kg for a children. The average residual concentration for each pesticide resulted from averaging the concentration found in the samples. EDI was calculated following the average vegetable $IR_{vegetable}$ of 0.400 kg $person^{-1}$ day^{-1} for an adult and 0.2 Kg for an adolescent, in fact the Food and Agriculture organization recommends a minimum daily intake of 400 g of fruits and vegetables per person to reduce the risk of chronic diseases like heart disease, cancer, and diabetes. Chronic dietary exposure risk (% ADI) was obtained as the ratio between the estimated daily intake (EDI) and the corresponding Acceptable Daily Intake (ADI, mg Kg^{-1} b.w.) sourced from the EU Pesticides Database. HQ values were quantified to establish the long-term effects on health owing the consume of pesticide residues from fruit and vegetables (Habib et al., 2021; Parven et al., 2021). Fruit and vegetables are considered safe when its HQ is below 1 while HQ exceeding this value indicates a potential health risk for consumers.

$$EDI= (C_i \times IR_{vegetable})/b_w$$

$$HQ = EDI/RfD$$

3. Results and discussion

In this study, 220 active ingredients in 475 vegetable samples collected in Sicily, Italy (Fig. 1) were quantified. Due to the large quantity of data obtained, this section only reports and discusses results relating to samples in which the quantities of active ingredients were

Fig. 1. – Sampling sites.

Table 1
Samples in which acetamiprid is greater than the limits of quantification.

Provenience	Vegetable	Concentration μg Kg^{-1}	Provenience	Vegetable	Concentration μg Kg^{-1}
Acireale	pear	130	Palermo	mandarins	12
Agrigento	solanaceae	800	Palermo	pepper	37
Alcamo	apricot	160	Palermo	pear	32
Assoro	solanaceae	74	Palermo	solanaceae	38
Bagheria	apple	50	Palermo	grape	150
Bagheria	pear	16	Piazza Armerina	peach 1	20
Caltanissetta	apricot	20	Piazza Armer	peach 2	30
Caltanissetta	peach 1	30	Pozzallo	orange	30
Caltanissetta	peach 2	30	Pozzallo	Cucumbers,courgettes	57
Castelbuono	grape	100	Ragusa	solanaceae	120
Catania	leafy vegetables	94	Rosolini	grape 1	130
Catania	pepper	50	Rosolini	grape 2	640
Catania	peach	60	Salemi	solanaceae	10
Catania	solanaceae	230	San Cataldo	apple	20
Enna	pear	20	Santa Croce C	solanaceae	13
Floridia	apricot	17	Siracusa	peach	30
Giarre	peach	15	Sortino	apple	32
Gibellina	apricot	80	Sortino	pear	36
Gravina Di Catania	apricot	27	Trapani	cucumbers, courgettes	120
Gravina Di Catania	peach	11	Trapani	peach	44
Ispica	cucumbers and courgettes	22	Trapani	grapefruits	55
Lercara Friddi	peach	18	Trapani	solanaceae	75
Licodia Eubea	grape 1	100	Venetico	solanaceae	9
Licodia Eubea	grape 2	170	Villabate	solanaceae	25
Messina	solanaceae	120	Vittoria	solanaceae 1	11
Misterbianco	lettuce roman	94	Vittoria	solanaceae 2	10
Misterbianco	pear	30	Vittoria	solanaceae 3	8
Monreale	apple	86	Vittoria	solanaceae 4	14
Noto	peach	24		**Min**	**8**
Pace Del Mela	solanaceae	30		**Max**	**800**

greater than the quantification limit, as shown in Tables 1,2,3,4,5,6,7,8,9,10.

Acetamiprid, an active ingredient belonging to the class of neonicotinoid insecticides, widely used to combat a variety of sucking and chewing pests (Wallace, 2024), was present in 58 of the analysed samples (Fig. 2). The concentrations in samples were between 0.008 ± 0.004 and 0.8 ± 0.2 mg Kg^{-1}. The highest concentrations were detected in solanaceae samples collected to Agrigento and in a grape sampled from Rosolini. Other Researchers (Li et al., 2024) found that Acetamiprid was the major constituent of pesticide residue in vegetables (69.4 %) and fruits (73.9 %). They quantified this compound at concentrations of 1.77 and 3.65 mg Kg^{-1} in fruits and green leafy vegetables, respectively, collected from various markets in Shenzhen between 2022 and 2023. Moreover, Acetamiprid has also been reported as the most detected pesticide in the top ten origin countries such as Turkey and India (Eissa et al., 2024). The Acetamiprid can cause chromosomal defects, genetic damage and antioxidant depletion (Phogat et al., 2022). Although this compound has not been shown to bio transform into harmful metabolites, it has recently been shown that it can be absorbed through intestinal cells, potentially resulting in accumulation in the body (Wallace, 2024). The RfD for acetamiprid is 0.005 mg Kg^{-1} body weight per day. This value was recently lowered from 0.025 mg Kg-1 bw day-1 by the European Food Safety Authority (EFSA) due to new toxicological data (COMMISSION, 2017).

Boscalid, is a biphenyl amide derived inhibitor of succinate dehydrogenase, a broad spectrum fungicide used in agriculture to protect crops from fungal diseases (Li et al., 2024), was quantified by us in 81 vegetable samples in the concentration range between 0.006 ± 0.002 and 2.0 ± 1.1 mg Kg^{-1}. In this case, the highest concentration was found in a sample of currants sampled in Belpasso, followed by strawberries sampled in Milazzo. Malhat et al. (2025) found concentrations of 0.29 mg Kg in Egyptian fruit samples.

Boscalid has low acute toxicity (Hertfordshire), the Codex Alimentarius database maintained by the FAO lists the maximum residue limits for it in various food products (W. FAO). The maximum Acceptable Daily Intake (RfD) for boscalid is 0.04 mg Kg^{-1} b.w. day^{-1} (Tzatzarakis et al., 2020). This quantity was recognized by the European Commission under Directive 91/414/EEC (Union) and is used for assessing potential long-term dietary risks from this active molecule exposure. An Acute Reference Dose (ARfD) was deemed unnecessary for boscalid.

Chlorpyrifos (Medicine) is an organophosphate compound, is widely used as acaricide, insecticide in households and agriculture (Medicine). In humans, this compound can inhibit cholinesterase, resulting in overstimulation of the nervous system causing nausea, dizziness, confusion, respiratory paralysis and, at very high exposures, death. Significant changes in plasma cholinesterase inhibition were observed in repeated doses of 0.1 mg Kg^{-1} of compound, but not in single doses (Medicine). The Acceptable Daily Intake (ADI) for chlorpyrifos is set at 0.001 mg Kg^{-1} of body weight per day, according to the National

Table 2
Samples in which Boscalid is greater than the limits of quantification.

Provenience	Vegetable	Concentration µg Kg^{-1}	Provenience	Vegetable	Concentration µg Kg^{-1}
Acireale	apricot	50	Milazzo	Culti. strawberries 2	50
Acireale	peach	50	Misterbianco	Cultivat strawberries	30
Agrigento	orange 1	9	Misterbianco	pear	50
Agrigento	orange 2	10	Misterbianco	solanaceae	6
Alcamo	carrots	70	Monreale	apple	230
Bagheria	apple	70	Monreale	plum	82
Bagheria	pear	180	Naro	pear	143
Barcellona Pozzo Di Gotto	orange	20	Palermo	cultivat strawberries	147
Barcellona Pozzo Di Gotto	pear	20	Palermo	pepper	120
Belpasso	orange	12	Palermo	plum	115
Belpasso	Ribes	2200	Paterno'	orange	32
Bronte	peach	200	Paterno'	carrots	70
Caltanissetta	orange	11	Piazza Ar.	lettuce	320
Caltanissetta	lettuce and similar	11	Piazza Ar.	plum	26
Caltanissetta	mandarins	9	Pozzallo	apricot	36
Caltanissetta	peach	640	Ragusa	orange 1	9
Caltanissetta	plum	34	Ragusa	orange 2	9
Campobello Di Mazara	lettuce	10	Ragusa	carrots	36
Canicatti'	cherry	200	Ragusa	pear	34
Canicatti'	cultivated strawberries	53	Ragusa	peach 1	70
Castelvetrano	solanaceae	34	Ragusa	peach 2	60
Catania	apricot	10	Ribera	solanaceae	20
Catania	orange	10	Santa Croce C	solanaceae	26
Catania	lettuce and similar	50	Santa Ninfa	pear	100
Catania	apple	30	Sciacca	orange	110
Catania	solanaceae	30	Scicli	solanaceae 1	60
Comiso	mandarins	18	Scicli	solanaceae 2	11
Enna	apricot	99	Serradifalco	grape	120
Enna	apple	60	Siracusa	apple	90
Enna	peach	20	Sortino	pear	55
Favara	carrots	15	Termini I.	plum	54
Favara	apple	70	Torregrotta	Cultivat.strawberries	60
Floridia	apricot1	40	Trapani	orange	12
Floridia	apricot2	110	Trapani	mandarin oranges	10
Gela	mandarins	17	Trapani	peach	220
Giarre	peach	20	Venetico	solanaceae	130
Gibellina	apple	150	Villabate	solanaceae	160
Leonforte	orange	18	Villabate	plum	200
Licata	orange	12	Villafranca S.	orange	8
Messina	cultivated strawberries	27		**Min**	**6**
Messina	solanaceae	170		**Max**	**2200**
Milazzo	cultivated strawberries 1	1200			

Table 3
Samples in which Chlorpyrifos is greater than the limits of quantification.

Provenience	Vegetable	Concentration μg Kg^{-1}	Provenience	Vegetable	Concentration μg Kg^{-1}
Agrigento	orange	12	Milazzo	lemon 1	179
Agrigento	lemon	60	Milazzo	lemon 2	120
Agrigento	mandarins	15	Misilmeri	mandarins	203
Assoro	solanaceae 1	14	Pachino	mandarins	25
Assoro	solanaceae 2	20	Palermo	mandarins	62
Barcellona Pozzo Di Gotto	medlar	13	Palermo	grapefruits	40
Caltanissetta	orange	189	Ragusa	lemon	140
Caltanissetta	mandarins	40	Salemi	solanaceae	90
Enna	fennel	110	Santa Flavia	lime	35
Enna	solanaceae	38	Scicli	mandarins	15
Ispica	grapefruits	700	Siracusa	Peach, hybrid	600
Licata	melon, pumpkin, watermelon	19	Termini Imerese	solanaceae	100
Licata	mandarins	120			
Messina	grapefruits 1	200		**Min**	**12**
Messina	grapefruits 2	24		**Max**	**700**

Table 4
Samples in which Cyhalothrin, lambda is greater than the limits of quantification.

Provenience	Vegetable	Concentration μg Kg^{-1}	Provenience	Vegetable	Concentration μg Kg^{-1}
Assoro	solanaceae	14	Palermo	peach and similar hybrids	30
Avola	peach and similar hybrids	13	Petrosino	pear	40
Caltagirone	apricot	35	Ragusa	peach and hybrids	35
Caltanissetta	apricot	70	Ragusa	celery	30
Caltanissetta	peach and similar hybrids	50	Rosolini	peach and hybrids	300
Caltanissetta	peach and similar hybrids	30	Salemi	peach and hybrids	57
Canicatti'	cherry	280	San Cataldo	peach and hybrids	17
Canicatti'	spinach and the like	32	Scicli	peach and hybrids	30
Castronovo Di Sicilia	peach and similar hybrids	50	Siracusa	peach and hybrids	100
Catania	lettuce iceberg	20	Siracusa	peach and hybrids	29
Enna	plum	20	Siracusa	peach and hybrids	11
Floridia	apricot	15	Sommatino	peach and hybrids	29
Floridia	peach and similar hybrids	150	Trapani	peach and hybrids	32
Giarre	peach and similar hybrids	20	Valguarnera	peach and hybrids	14
Giarre	peach and similar hybrids	36	Zafferana E.	apricot	40
Misilmeri	peach and similar hybrids	30			
Pachino	peach and similar hybrids	33		**Min**	**11**
Palermo	apricot	24		**Max**	**300**
Palermo	beans	40			

Table 5
Samples in which Cyprodinil is greater than the limits of quantification.

Provenience	Vegetable	Concentration μg Kg^{-1}	Provenience	Vegetable	Concentration μg Kg-1
Avola	grape	90	Ragusa	solanaceae	20
Belpasso	solanaceae	50	Salemi	peach and hybrids	600
Caltanissetta	grape	54	San Cataldo	apple	20
Canicatti'	peach and similar hybrids	130	San Cataldo	peach and hybrids	340
Carini	grape	200	Santa Croce Camerina	solanaceae	24
Catania	apricot	16	Santa Croce Camerina	solanaceae	16
Enna	peach and similar hybrids	32	Santa Croce Camerina	solanaceae	44
Enna	peach and similar hybrids	30	Scicli	solanaceae	26
Lercara Friddi	peach and similar hybrids	42	Scicli	solanaceae	50
Licodia Eubea	grape	70	Serradifalco	grape	1100
Licodia Eubea	grape	350	Serradifalco	grape	400
Messina	cultivated strawberries	52	Siracusa	apple	360
Messina	solanaceae	43	Siracusa	peach and hybrids	60
Pachino	peach and similar hybrids	116	Trapani	peach and hybrids	460
Pachino	peach and similar hybrids	20	Trapani	solanaceae	12
Pachino	grape	500	Trapani	solanaceae	21
Palazzolo Acreide	cultivated strawberries	110	Villafranca Tirrena	lettuce	55
Palermo	cucumbers and courgettes	10	Vittoria	solanaceae	184
Palermo	grape	250	Vittoria	solanaceae	20
Petralia Soprana	grape	210	Vittoria	solanaceae	7
Piazza Armerina	peach and similar hybrids	50			
Priolo Gargallo	solanaceae	140		**Min**	**7**
Ragusa	fennel	98		**Max**	**1100**
Ragusa	parsley	770			

Table 6
Samples in which Cis Deltametrin is greater than the limits of quantification.

Provenience	Vegetable	Concentration µg Kg^{-1}	Provenience	Vegetable	Concentration µg Kg-1
Acireale	cherry	150	Piazza Armerina	peach and hybrids	17
Agrigento	peach and hybrids	140	Pozzallo	apricot	70
Assoro	solanaceae	14	Pozzallo	peach and hybrids	120
Avola	peach and hybrids	56	Ragusa	lettuce	22
Belpasso	Cultivated Ribes	50	Ragusa	peach and hybrids	12
Caltanissetta	apricot	78	Ragusa	parsley	60
Caltanissetta	lettuce	820	Ragusa	plum	20
Caltanissetta	peach and hybrids	13	Riesi	apricot	20
Caltanissetta	peach and hybrids	60	Rosolini	mandarins	40
Caltanissetta	peach and hybrids	160	Rosolini	pear	30
Caltanissetta	peach and hybrids	12	Salemi	peach and hybrids	66
Canicatti'	peach and hybrids	120	San Giovanni La Punta	cherry	300
Castelvetrano	peach and hybrids	14	Sciacca	cultivated strawberries	100
Catania	lettuce ICEBERG	30	Scicli	peach and hybrids	86
Enna	peach and hybrids	16	Serradifalco	grape	40
Enna	peach and hybrids	24	Siracusa	peach and hybrids	80
Ferla	peach and hybrids	80	Siracusa	peach and hybrids	260
Floridia	peach and hybrids	30	Siracusa	peach and hybrids	120
Giarre	peach and hybrids	150	Siracusa	peach and hybrids	120
Gravina Di Catania	peach and hybrids	40	Siracusa	solanaceae	12
Misilmeri	apricot	57	Sommatino	prickly pear	14
Misilmeri	peach and hybrids	30	Sommatino	peach and hybrids	64
Misterbianco	pear	15	Trapani	apricot	20
Misterbianco	peach and hybrids	80	Trapani	peach and hybrids	70
Modica	cherry	60	Trapani	peach and hybrids	31
Modica	pear	150	Tremestieri Etneo	apricot	30
Modica	peach and hybrids	148	Valguarnera Caropepe	peach and hybrids	22
Pachino	mandarin oranges	12	Zafferana Etnea	plum	20
Palermo	peach and hybrids	20			
Paterno'	pear	40		**Min**	**12**
Piazza Armerina	apricot	45		**Max**	**40**
Piazza Armerina	lettuce	60			
Piazza Armerina	peach and hybrids	160			

Table 7
Samples in which Etofenprox is greater than the limits of quantification.

Provenience	Vegetable	Concentration µg Kg^{-1}	Provenience	Vegetable	Concentration µg Kg^{-1}
Acireale	apricot	29	Misterbianco	pear	30
Assoro	solanaceae	14	Modica	peach and hybrids	269
Avola	peach and hybrids	30	Pace del Mela	Kiwi	100
Caltanissetta	peach and hybrids	138	Pachino	peach and hybrids	120
Caltanissetta	peach and hybrids	400	Palagonia	peach and hybrids	70
Caltanissetta	peach and hybrids	138	Palermo	apricot	30
Carini	lotus	100	Palermo	plum	20
Castellammare Del Golfo	peach and hybrids	140	Piazza Armerina	peach and hybrids	28
Castelvetrano	peach and hybrids	420	Ragusa	apricot	230
Castelvetrano	peach and hybrids	200	Ragusa	peach and hybrids	300
Catania	lettuce ICEBERG	80	Salemi	peach and hybrids	150
Enna	peach and hybrids	17	Scicli	peach and hybrids	40
Enna	peach and hybrids	59	Scordia	apricot	280
Enna	peach and hybrids	233	Serradifalco	grape	14
Giarre	peach and hybrids	130	Sommatino	peach and hybrids	148
Giarre	peach and hybrids	80	Termini Imerese	apple	86
Giarre	peach and hybrids	80	Trapani	peach and hybrids	322
Ispica	grapefruits	74	Villabate	plum	22
Lercara Friddi	peach and hybrids	85			
Lercara Friddi	peach and hybrids	80		**Min**	**14**
Misilmeri	apricot	249		**Max**	**420**
Misterbianco	prickly pear	60			

Institutes of Health (EFSA, 2019). This value represents the estimated daily intake of chlorpyrifos that is considered safe for humans over a lifetime. In households, it is used to control cockroaches, fleas and termites, is also content in some flea and tick collars for pets. In agriculture, it is employed to control ticks on cattle and as a spray to control crop pests. In analysed samples, *chlorpyrifos* was detected in 27 samples (Fig. 2). The highest concentration (0.7 ± 0.2 mg Kg^{-1}) was detected in a grapefruits sample collected in Ispica. In literature is reported that in fresh fruit and vegetables from Croatian market residues of chlorpyrifos were in the range 0.03–0.67 mg Kg^{-1} (Knežević and Serdar, 2009). Kumar et al. analysed about 20 % of all vegetable samples collected from farms and markets in 21 districts of Haryana (one of India's leading agricultural states, which supplies fruit and vegetables to Delhi) using GC-MS. They found chlorpyrifos in concentrations ranging from the detection limit to 6.2 mg Kg^{-1}. Other authors (Yuan et al., 2014) found high detection rates of chlorpyrifos in celery, cowpeas, Chinese cabbage

Table 8
Samples in which Hexythiazon is greater than the limits of quantification….

Provenience	Vegetable	Concentration µg Kg^{-1}	Provenience	Vegetable	Concentration µg Kg^{-1}
Caltanissetta	mandarins	13	Realmonte	solanaceae	19
Canicatti'	cultivated strawberries	120	Riesi	apricot	24
Carini	solanaceae	14	Rosolini	solanaceae	30
Catania	solanaceae	46	Rosolini	solanaceae	110
Enna	cultivated strawberries	34	Scicli	solanaceae	6
Enna	peach and similar hybrids	46	Siracusa	solanaceae	58
Enna	solanaceae	46	Trapani	peach and similar hybrids	44
Mazzarino	solanaceae	26	Trapani	solanaceae	7
Messina	solanaceae	12	Trapani	solanaceae	46
Messina	solanaceae	14	Tremestieri Etneo	apricot	38
Milazzo	cultivated strawberries	130	Villabate	cultivated strawberries	520
Pace del Mela	cultivated strawberries	97	Villabate	solanaceae	25
Pachino	solanaceae	60	Vittoria	solanaceae	77
Palermo	cultivated strawberries	550	Vittoria	solanaceae	19
Palermo	pepper	88	Vittoria	solanaceae	6
Piazza Armerina	solanaceae	38	Vittoria	solanaceae	12
Porto Empedocle	mandarins	28			
Ragusa	cultivated strawberries	47		**Min**	**6**
Ragusa	solanaceae	70		**Max**	**550**
Realmonte	mandarins	24			

Table 9
Samples in which Imazalil is greater than the limits of quantification.

Provenience	Vegetable	Concentration µg Kg^{-1}	Provenience	Vegetable	Concentration µg Kg^{-1}
Acireale	solanaceae	220	Ispica	solanaceae	950
Agrigento	solanaceae	500	Licata	solanaceae	20
Agrigento	solanaceae	830	Mazara Del Vallo	solanaceae	570
Agrigento	solanaceae	380	Mazara Del Vallo	solanaceae	220
Alcamo	solanaceae	99	Messina	solanaceae	160
Alcamo	solanaceae	15	Messina	solanaceae	400
Barcellona Pozzo Di Gotto	solanaceae	220	Racalmuto	solanaceae	95
Caltanissetta	solanaceae	1085	Ragusa	solanaceae	54
Caltanissetta	solanaceae	17	Ravanusa	solanaceae	140
Canicatti'	solanaceae	84	San Cataldo	solanaceae	1300
Castelvetrano	solanaceae	300	Scicli	solanaceae	960
Catania	solanaceae	210	Trapani	solanaceae	1100
Enna	solanaceae	22			
Enna	solanaceae	290		**Min**	**6**
Favara	solanaceae	1600		**Max**	**1770**
Ispica	solanaceae	1770			

and lettuce, at 23 %, 19 %, 15 % and 11 %, respectively. The highest residues were found in lettuce (3.47 mg Kg^{-1}), cabbage (3.02 mg Kg^{-1}), carrots (2.90 mg Kg^{-1}) and radishes (1.69 mg Kg^{-1}). Chlorpyrifos was not detected in green tea, carrots, tomatoes, rice and maize by researchers (Altunay et al., 2025) in vegetables purchased from local supermarkets in Sivas (Turkey) because the amounts were lower than the LOD of the method. The highest amount was found in spring onions (0.017 ± 0.0008 mg Kg^{-1}).

In Egyptian fruit samples (Malhat et al., 2025), concentrations of the above-mentioned active ingredient were quantified between LOQ and 0.153 mg Kg^{-1}, while in green beans sampled in a Mohasthan (Bangladesh) bazar was 0.028 mg Kg^{-1} (Parven et al., 2021).

In humans, this compound can inhibit cholinesterase, resulting in overstimulation of the nervous system causing nausea, dizziness, confusion, respiratory paralysis and, at very high exposures, death. Significant changes in plasma cholinesterase inhibition were observed in repeated doses of 0.1 mg Kg^{-1} of compound, but not in single doses (Medicine). The Acceptable Daily Intake (ADI) for chlorpyrifos is set at 0.01 mg/Kg of body weight per day, according to the National Institutes of Health (EFSA, 2019; Clegg and van Gemert, 1999). This value represents the estimated daily intake of chlorpyrifos that is considered safe for humans over a lifetime.

λ-Cyhalothrin, was found in 34 samples (Fig. 2), ranged from 0.01 ± 0.003–0.3 ± 0.1 mg Kg^{-1} and, the highest concentration was found in a sample of peaches sampled in Rosolini.

Cyprodinil, belonging to the anilinopyrimidine class, is a systemic fungicide with a broad action spectrum. It interferes in the biosynthesis of amino acids, preventing the growth and spread of pathogens. Cyprodinil was content in more than 10 % of the vegetables analysed by us in a wide range of concentrations, in particular in the grapes sampled at Serradifalco the maximum concentration (1.1 ± 0.3 mg Kg^{-1}) was found. The ADI (Acceptable Daily Intake) for lambda-cyhalothrin for humans is 0.0025 mg/Kg body weight per day, according to EFSA ((EFSA), 2024).

Deltamethrin, belonging to the pyrethrum class, having insecticidal and acaricidal action, was found in 61 samples (Fig. 2), however, in most of which the concentrations did not exceed 0.3 mg Kg^{-1} except for salad lettuce when did it reach 0.8 ± 0.17 mg Kg^{-1}. In literature is reported that residues of deltamethrin were found in 72 samples out of a total of 5560 of fresh vegetables imported into the United Arab Emirates (Osaili et al., 2022), while, in only two samples of fruits and vegetables from the Aegean region (Turkey) was found in the range 0.01–0.078 mg Kg^{-1} (Bakırcı et al., 2014). The World Health Organization classifies this active ingredient as moderately toxic. In commercial products authorized in Italy it is classified as harmful or not classified, depending on the concentration (Italiana, 2007). Some researchers (Pandya et al., 2025)

Table 10
Samples in which Tebuconazole is greater than the limits of quantification.

Provenience	Vegetable	Concentration µg Kg^{-1}	Provenience	Vegetable	Concentration µg Kg^{-1}
Agrigento	peach and hybrids	30	Pachino	solanaceae	100
Barcellona Pozzo Di Gotto	cucumbers and courgettes	135	Palermo	apricot	40
Bronte	pear	20	Palermo	apricot	20
Bronte	peach and hybrids	42	Palermo	peach hybrids	120
Caltanissetta	solanaceae	20	Patti	medlars	67
Caltanissetta	solanaceae	62	Piazza Armer	apple	19
Caltanissetta	peach and hybrids	60	Piazza Armer	peach hybrids	90
Caltanissetta	plum	18	Prizzi	apricot	11
Canicatti'	solanaceae	105	Ragusa	apricot	58
Canicatti'	peach and hybrids	200	Salemi	peach hybrids	100
Carini	peach and hybrids	400	Salemi	plum	38
Castronovo Di Sicilia	peach and hybrids	18	Santa Croce C	solanaceae	90
Catania	solanaceae	17	Santa Croce C	solanaceae	150
Catania	cabagge	470	Santa Ninfa	pear	16
Catania	peach and hybrids	17	Sciacca	apricot	24
Enna	onion	12	Scicli	solanaceae	11
Enna	peach and hybrids	110	Scordia	apricot	63
Enna	plum	100	Serradifalco	plum	60
Erice	medlars	38	Siracusa	cherry	330
Ferla	peach and hybrids	236	Siracusa	apple	24
Floridia	solanaceae	50	Siracusa	peach hybrids	84
Floridia	peach and hybrids	220	Siracusa	peach hybrids	96
Giarre	peach and hybrids	67	Siracusa	solanaceae	42
Gravina Di Catania	solanaceae	68	Trapani	apricot	24
Ispica	peach and hybrids	30	Trapani	peach hybrids	170
Lercara Friddi	peach and hybrids	56	Tremestieri E.	apricot	72
Mazara Del Vallo	cucumbers and courgettes	22	Villabate	solanaceae	20
Messina	peach and hybrids	40	Villabate	plum	640
Misilmeri	apricot	12	Vittoria	solanaceae	51
Misilmeri	apricot	150	Vittoria	solanaceae	40
Misilmeri	peach and hybrids	28	Zafferana Etnea	apricot	170
Misilmeri	peach and hybrids	48			
Modica	pear	40		**Min**	**11**
Modica	peach and hybrids	170		**Max**	**640**
Noto	peach and hybrids	140			

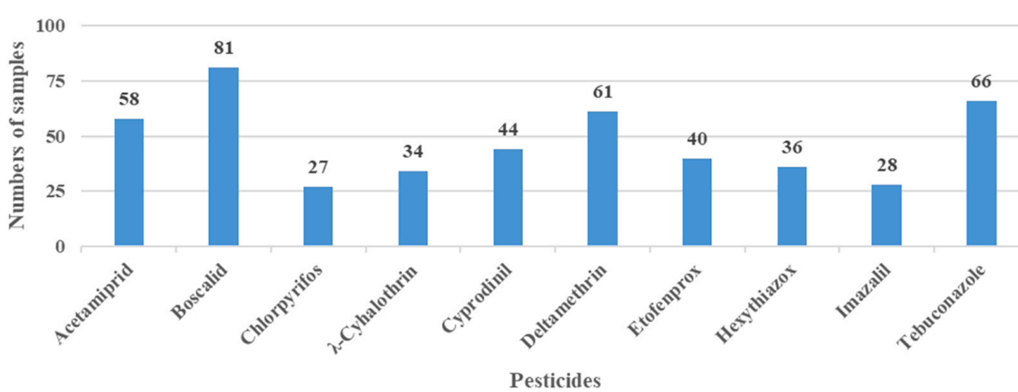

Fig. 2. Number of samples in which the active ingredient was quantified.

have established that exposure to sub-lethal levels (0.275 ppm) of deltamethrin produces non-negligible harmful effects on *Digitonthophagus gazella*, a species of dung beetle. In 30 days, exposure to the aforementioned active ingredient damages the antioxidant defense system, causing the imbalance of the enzyme activity essential to limit oxidative damage. This imbalance increases oxidative stress, cellular damage and cases of inflammation. Prolonged exposure increases the aforementioned effects, producing histological alterations in important organs such as the intestine, brain, testes and ovaries. Another research (Altun et al., 2025), performing experiments on rats, considers brain damage in rats exposed to DLM, concluding that exposure may play a significant role in the pathogenesis of dementia.

Etofenprox was found in 40 samples (Fig. 2) with the highest concentrations (0.42, 0.40, 0.32 mg Kg^{-1}) were quantified in peach samples. The RfD for etofenpox is 0.03 mg Kg^{-1} body weight per day (Tzatzarakis et al., 2020).

Hexythiazox, an acaricidal used to control eggs, larvae and nymphs of many miteswas present in high concentrations only in two strawberries samples purchased at Palermo (0.55 ± 0.12 mg Kg^{-1}) and at Villabate (0.52 ± 0.10 mg Kg^{-1}), while in all the other samples it was less than 0.13 mg Kg^{-1}. Hispanic researchers (Blasco et al., 2006) analysing 160 orange and tangerine samples from an agricultural cooperative of the Valencian Community (Spain) found hexythiazox concentration in the 0.018–3.75 mg Kg^{-1} range. The RfD for hexythiazox is 0.025 mg Kg^{-1} body weight per day (USEPA, 2020).

Imazalil, was found in a wide range of concentrations (0.06 ± 0.02 mg Kg^{-1}- 1.8 ± 0.25 mg Kg^{-1}) in 28 samples of solanaceae with the highest concentration of 1.8 mg Kg^{-1}. The RfD for this active compound is 0.108 mg Kg^{-1} body weight per day (USEPA, 2020).

Tebuconazole was found in 66 samples (Fig. 2). The maximum concentration (0.64 ± 0.18 mg Kg^{-1}) was quantified in a plum sample sampled at Villabate. A recent study (Huang et al., 2022) showed that this active molecule and its major metabolite reduced heart rate, inhibited hatching, and pericardial cysts in zebrafish embryos. Other experiments with acridine orange revealed cellular apoptosis in the area surrounding the cardiac regions of zebrafish larvae. In addition, the expression levels of apoptosis-related genes also varied significantly. Some researchers (Bellot et al., 2025) established that chronic exposure (9 months) to tebuconazole considerably altered the reproduction of sparrows (especially females), in particular, chicks from the exposed group showed reduced growth and a higher mortality rate. The authors conclude that tebuconazole could be harmful to the reproduction of farmed birds. The RfD for this active compound is 0.108 mg Kg^{-1} body weight per day.

Boscalid was the most frequently detected pesticide, found in 18 % of samples (81/475). It is an active ingredient, with preventive and curative action that interferes with the cellular respiration of fungi, used for the control of some diseases, such as gray mold. Boscalid in Sicily is used in vine, against the monilia of fruit trees (peach, nectarine, apricot, plum, cherry). It is also effective against botrytis of strawberries, vegetables (broccoli, cauliflower, lettuce, spinach, chard) and other small fruits. The occurrence of pesticide residues in fruit and vegetables samples are shown in Fig. 2.

3.1. Statistical and chemometric analyses

Correlation analysis is a fundamental statistical tool used in residual analyses of pesticides to evaluate relationships between chemical analytes. In detail, in agricultural contexts, multiple pesticide and fungicide residues can co-exist within the same sample due to combined use, environmental persistence, or transformation. Understanding how these analytes correlate provides insight into usage patterns, potential combined exposure risks, and implications for regulation and monitoring.

The correlation matrix concerning conducted on positive results detected in analysed samples is reported in Figure 13 of the Supplementary Section: In detail, correlation matrix involving several analytes: Acetamiprid, Boscalid, Chlorpyrifos,Cyhalothrin lambda,Cyprodinil, Deltamethrin (cis-deltamethrin), Etofenprox, Hexythiazox, Imazalil and Tebuconazole.

The correlation matrix reveals that certain analytes are likely to show higher positive correlations, suggesting a tendency to appear together in the same samples. This co-occurrence can be attributed to agricultural practices, such as the use of premixed formulations or the simultaneous application of multiple agents for pest and disease control. For example, Imazalil and Chlorpyrifos exhibit strong correlations p-value (< 0.05), particularly in crops where a combined insecticidal strategy is employed. Their co-presence may reflect standard integrated pest management practices, where both systemic and contact insecticides are used for broader efficacy. Similar correlations were found comparing Etofenprox with Cyprodinil and Etofenprox with Deltamethrin.

To highlight potential correlations among samples or analytes a Principal Component Analysis (PCA) was performed (Figure 14 of the Supplementary Section).

PCA is widely used to reduce the dimensionality of complex datasets by transforming a set of potentially correlated variables into a new set of uncorrelated variables, known as principal components. Prior to conducting the PCA, the data were normalized by centering around the mean value. In the present study, PCA analysis was carried out on concentrations of 11 analytes detected in 248 samples. A cumulative variance of 45.03 was explained by three eigenvectors–principal components. The first principal component (PC1) explain 13.3 % of the total variance, second component (PC2) explain 11.9 % while the third component (PC3) explain 9.8 %. In Figure 14 of the Supplementary Section, it is reported that PCA analysis results using the first three Principal Components.

As shown in Fig. 14, PC1 explain samples characterized by Imazalil and Chlorpyrifos while PC2 explain samples characterized by, Cyhalothrin lambda, Cyprodinil,Deltamethrin (cis-deltamethrin), Etofenprox, and Tebuconazole. Interesting to underline that Citrus samples show a good discrimination whit pesticide characterized to positive value of PC1 (Imazalil and Chlorpyrifos), while strawberries samples are discriminated whit pesticide characterized to negative PC1 value.

4. Conclusions

This investigation assessed the presence of 220 pesticide residues in 475 vegetable samples collected across 90 locations in Sicily, using QuEChERS extraction methods followed GC-MS/MS and LC-MS/MS analyses. The analytical protocols demonstrated good sensitivity and selectivity, with determination coefficients (R^2) greater than 0.998 for all analytes. Recovery percentages for different pesticides ranged between 60 % and 140 %, ensuring reliability in quantification.

Out of the 475 analyzed samples, 206 (43.4 %) contained pesticide residues above the limit of quantification. The most frequently detected active ingredient was Boscalid, found in 81 samples (17 %) at concentrations ranging from 0.006 ± 0.002–2.0 ± 1.1 mg Kg^{-1}, with the highest levels observed in currants and strawberries. Acetamiprid was detected in 58 samples, especially in solanaceae crops and grapes, with concentrations up to 0.8 ± 0.2 mg Kg^{-1}, exceeding the ADI (0.005 mg Kg^{-1} bw day^{-1}) in some cases. Deltamethrin was present in 61 samples, with the highest concentration (0.8 ± 0.17 mg Kg^{-1}) detected in lettuce.

Other frequently detected compounds included Chlorpyrifos (27 samples, max concentration: 0.7 ± 0.2 mg Kg^{-1}), Tebuconazole (66 samples, max 0.64 ± 0.18 mg Kg^{-1}), and Imazalil (28 samples, max 1.8 ± 0.25 mg Kg^{-1}). Moreover, a patterns revealed common combinations such as Imazalil–Chlorpyrifos and Etofenprox–Deltamethrin, suggesting synergistic or integrated application strategies.

By comparing the concentrations of the active ingredients in the samples with the maximum values reported by the European Community (Comunity) and the experimental uncertainties, all the samples, with the exception of one of peaches and another of prickly pears, whose concentrations of Chlorpyrifos and Etofenprox were above the legal limits (Chlorpyrifos MRL = 0.08 mg/kg, Etofenprox MRL = 0.01 mg/kg), we can conclude that the others comply with European legislation.

Unlike what was observed by other researchers Bhandari et al. (2019) who found HQ> 1 values for some active ingredients in samples of aubergines and chili peppers, in our case, considering the average concentrations of the active ingredients found in the investigated fruit and vegetable samples, it can be concluded that the HQ values for all the pesticides studied are below the established threshold of 1 for both adults and children. Consequently, the population exposed to pesticides through fruit and vegetable consumption can be considered safe. Only in the case of boscalid in a blackcurrant sample, the HQ value was slightly higher than 1.

CRediT authorship contribution statement

Santino Orecchio: Writing – original draft, Investigation, Data curation. **Giuseppe Domenico Arrabito:** Writing – original draft, Validation. **Diana Amorello:** Writing – original draft, Validation. **Francesca Di Gaudio:** Validation, Data curation. **Salvatore Barreca:** Writing – original draft, Validation, Software, Data curation. **Silvia Orecchio:** Writing – original draft, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jfca.2025.108573.

Data availability

No data was used for the research described in the article.

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