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Quality Parameters of Plum Orchard Subjected to Conventional and Ecological Management Systems in Temperate Production Area

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Abstract: Environmental protection, global food security, and nutritional quality are critical issues for worldwide sustainable development. Plums (*Prunus domestica* L.), well-known for their rich nutritional content and distinct phytochemical profile, have received increased attention due to their potential health benefits. The present study evaluates the ecological and conventional management systems of quality parameters in three plum varieties—Tuleu Gras, Record, and Centenar—and establishes suitable practices to improve fruit quality and yields. The fruit morphometric features (color, firmness, soluble solid content, titratable acidity, and total sugar) were analyzed during their raw fruit state, while different fruit-sample extracts were assessed for phytochemical compounds and heavy metal concentrations, specifically, zinc, copper, nickel, and cadmium. The results show a wide variability in the examined characteristics among management practices that differentially accumulated throughout the ripening phase and significantly influenced the nutritional value of the plum fruit. The application of an ecological management practice yielded small plum fruits (38 g) and maintained a more consistent and vigorous fruit color compared with the conventional system (83 g). Moreover, ecological plums have higher antioxidant activities, total polyphenols, and flavonoids (21.70–25.54 μ M Trolox/g of dw, 3.89–7.76 mg GAE/g of dw, and 1.45–3.65 mg CE/g of dw, respectively). Among the content of metals in the plum fruit, copper exhibited the highest concentrations (0.83–1.21 mg/kg), while cadmium was detected at the lowest levels (0.006–0.009 mg/kg). The potential health implications of heavy metals, by calculating their estimated daily intake (EDI), target hazard quotient (THQ), and hazard index (HI), for both adults and children were also analyzed. The EDI values of accumulated elements in the plum fruits followed the order of Cu > Zn > Ni > Cd with no concern for human health (THQ and HI < 1). According to this study’s findings, fruit quality parameters are significantly higher in ecological plums, providing a compelling argument for adopting sustainable agricultural practices. These results highlight the importance of selecting sustainable agricultural practices, not only to safeguard the environment but also to ensure high-quality products suitable for human consumption.

Keywords: plum orchard; phytochemicals; potential health benefits; heavy metals; health risk



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1. Introduction

Plum (*Prunus domestica* L.) is an important fruit, belonging to the *Prunus* genus, the subgenus *Prunus*, and the family *Rosaceae*, and is cultivated extensively in Asia, Europe, and North America. Plums are appreciated for their flavor as well as for their potential health benefits and are rich in essential nutrients [1]. The global production of plums is over 12.6 million tons annually, highlighting their importance as an increasingly popular fruit product among consumers [2]. The European variety of this fruit is particularly important

in temperate climates and can be found throughout Europe, from the southern regions to the northernmost parts [1]. In Romania, plums are both culturally and historically significant and are currently responsible for approximately half a million tons of plum production per year (www.worldpopulationreview.com, 23 April 2024).

Following a global trend, Romania has experienced an increase in plum production due to its great financial potential. Furthermore, the area of plum surfaces has risen in recent years, and many new plum orchards are being ecologically grown, since consumers worldwide demand ecological products for their health status and environmental benefits, as well as for their enhanced flavor compared to conventionally established alternatives [3].

Since market development and consumers are directed towards prioritizing their food's flavor and nutritional content, establishing the quality parameters, antioxidant activity, and heavy metal content of plum fruits has become pivotal. These fruits are rich in antioxidants, such as vitamins C and K, polyphenols, and flavonoids, which can counteract free radicals and shield cells from oxidative damage. The relationship between heavy metals and the antioxidant activity of plum fruits can be understood through the mechanism of action of antioxidants. When entering the body, heavy metals can generate free radicals and reactive oxygen or nitrogen species, damaging DNA, proteins, and cell lipids. The antioxidants in plum fruits act as protective shields, neutralizing these free radicals and thus preventing cell damage [4]. Plums are particularly beneficial for cardiovascular health due to their high fiber and potassium content and their ability to reduce cholesterol levels [5]. Other research has shown that bioactive compounds, such as polyphenols, flavonoids, anthocyanins, and vitamin C, exhibit notable antioxidant potential [6] and have numerous health benefits, such as anti-proliferative activity against breast cancer, immune-boosting properties, hypoglycemic effects, and the mitigation of age-related cognitive decline, and anticancer properties [1,7–9].

Analyzing the quality parameters of plum fruits involves a comprehensive evaluation of their visual appeal and firmness. Furthermore, sugar content, acidity levels, and volatile compounds contribute to the complex flavor profile that distinguishes plum varieties. Understanding these parameters not only aids in determining consumer preferences but also guides growers and producers in optimizing cultivation and post-harvest practices [10].

In addition to their sensory characteristics, plum fruits' antioxidant capacity has become a significant field of study. Researchers have examined the antioxidant activity and total phenolic component content of several plum cultivars [11,12]. The goal is to identify plum types high in antioxidants, which could potentially positively impact human health. Plums are a type of fruit that has a significant amount of phenolic compounds, which are known for their high antioxidant activity. Plums have a higher antioxidant activity compared to fruits such as oranges, apples, and strawberries [13,14]. Understanding the total antioxidant capacity of plants, which refers to the combined ability of various components in food to remove harmful free radicals, would be valuable for epidemiological studies. The total antioxidant capacity is considered a fundamental indicator of the biological value of dietary products [15].

Quality parameters encompass a spectrum of attributes, ranging from physical characteristics, such as color, size, and texture, to intrinsic factors, like the heavy metal content, sugar content, acidity, and aroma [16].

In modern society, exposure to heavy metals has become a significant human health concern. Metals such as lead, mercury, and cadmium can enter the body through various sources, such as food, water, and environmental pollution. These substances cause oxidative stress, damaging cells and contributing to chronic conditions such as cardiovascular disease, cancer, and neurological disorders. However, nature seems to offer solutions to counteract the harmful effects of heavy metals, and plum fruits stand out as an important ally in the fight against oxidative stress [5,17]. Research indicates that regularly eating plums can help lower heavy metal levels in the body, providing a detoxifying effect [18]. The antioxidants in these fruits may also help maintain the health of the cardiovascular system, reducing the risk of chronic diseases associated with exposure to heavy metals [19].

While certain research has indicated that ecological soils tend to have higher nutrient contents than conventionally treated soils, the overall findings have been inconsistent. The study conducted by Herencia et al. [20] examines the lasting impacts of ecological and conventional management methods on soil quality in Japanese plum orchards. The study specifically focuses on evaluating chemical and biological indicators. The results suggest that implementing ecological management approaches has a beneficial impact on soil quality indicators, leading to improved biotic interactions and sustainability in agricultural systems. Other scientists discovered contradictory data on the biological communities linked to various management strategies, in which there were only minor variations in the soils and no consistently notable variations in the parameters examined [21]. Notwithstanding these discrepancies, some studies have indicated that the application of cover crops or ecological amendments changed the quality of the soil [22]. Nevertheless, not much is known about the long-term impacts of ecological management techniques and how they modify the physical, chemical, and biological characteristics of the soil in fruit cropping systems, such as plum orchards.

This study evaluates the physicochemical quality parameters, phytochemical characteristics, heavy metal concentrations, and antioxidant activity in plum fruits cultivated under different management systems, with the aim of demonstrating their nutritional value and highlighting the necessity of monitoring heavy metal pollution throughout the growing process to safeguard public health.

2. Materials and Methods

2.1. Research Area Description

The studied plum orchard (Tuleu Gras, Centenar, and Record variety) was part of a long field experiment established in 2014 and conducted at the Horticulture Research Field, Adamachi, at IULS (the University of Life Sciences) in Iasi, Romania (47°15' N–27°30' E). The research field is located in Jijia Plain, a subunit of the Jijia–Bahlui Plain. This region is part of the Moldavian Plateau and is characterized by hills with an elevation of 80–95 m.

According to soil taxonomy, the soil of the experimental field is aric-cambic chernozem, with a loamy clay texture and a pH of 6.65. The content of humus corresponds to 4.05% with a cationic exchange capacity of 19.03 me/100 g of soil [23].

The climate is temperate humid subtropical— C_{fa} , according to the Köppen climate classification—with a mean annual temperature and precipitation of 518 mm and 10 °C, respectively (<https://climateknowledgeportal.worldbank.org/country/romania>, 23 April 2024). The environmental conditions during this period are represented in Figures 1 and 2 (<https://www.fieldclimate.com>, 1 May 2024).

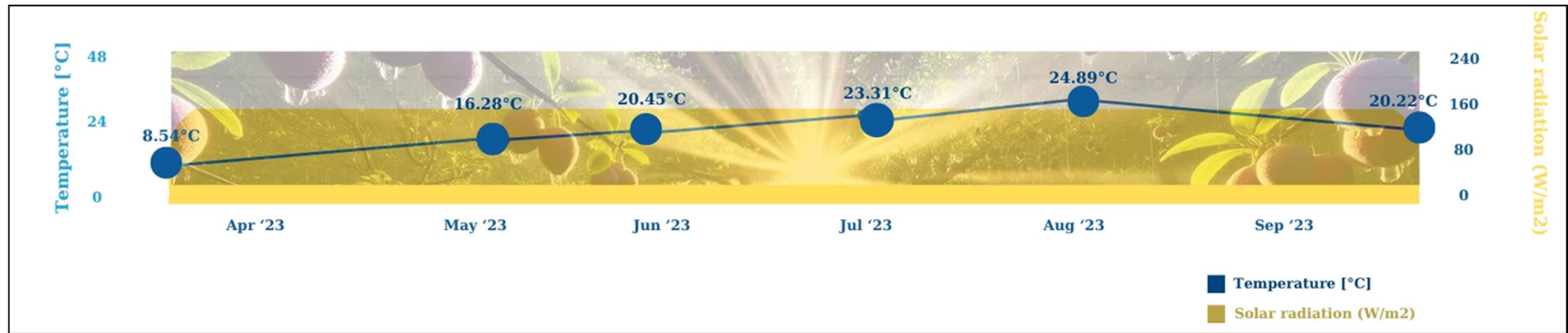


Figure 1. The monthly variations in temperature (°C) and solar irradiance (W/m²) throughout the growth period.

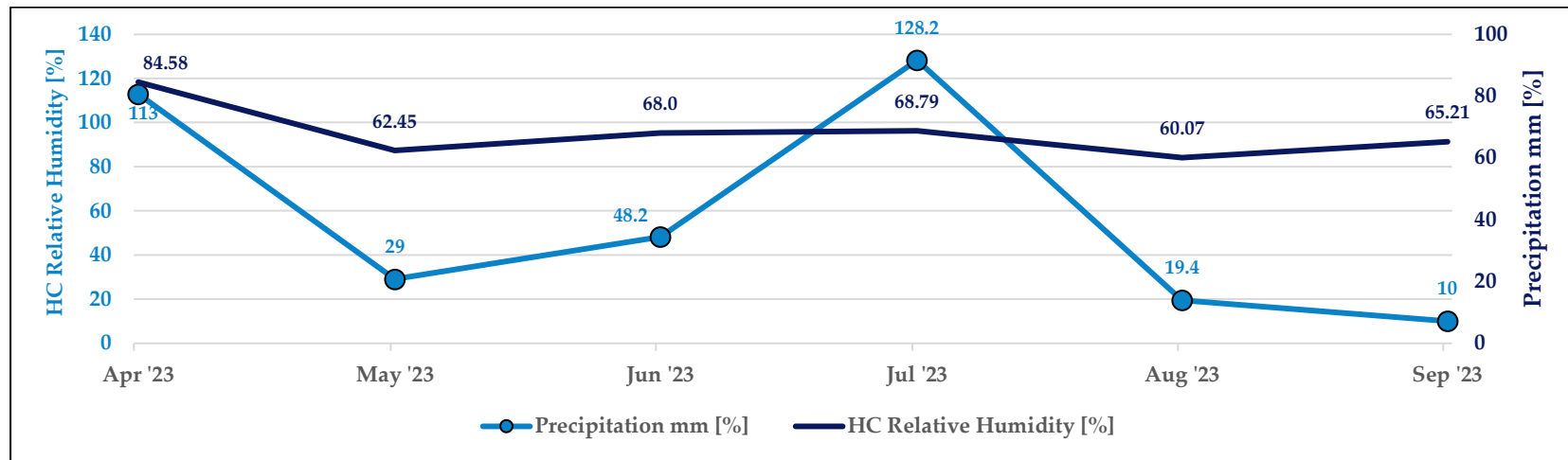


Figure 2. The precipitation (mm) and relative humidity (%) during the growth period.

2.2. Experimental Setup and Tillage Management Practices

To investigate the responses of plum quality attributes under conventional and ecological management systems, a field experiment was established to reveal the factors that influence changes in plum quality through different management practices. The studied plum orchard was 10 years old and was planted with the “Tuleu Gras, Centenar, and Record variety” at a spacing of 5 m × 5 m. The experimental plots were arranged using a randomized block design. The management practices were replicated three times, and each replicate contained 40 plum trees. Each plot covered an area of 5500 m². All plots were divided by 5 m-wide buffer strips.

In the ecological management system, plum trees were fertilized annually, with equivalent rates of 2 kg of copper (Cu) and potassium (K) sulfate, as well as zinc (Zn) and iron (Fe) as chelates. Organic fertilizers, at a dose of 600 kg ha⁻¹ (490 g ha⁻¹ NH₄, 1400 g ha⁻¹ P₂O₅, and 910 g ha⁻¹ K₂O), were applied two times per season (March and June), where K was applied in September. For weeds, manual weeding was used, while for pest control, foliar sprays of copper (fungicide) and paraffinic oil (acaricide/insecticide) were applied.

In the conventional plum orchard, fertilization was applied by the use of 11-15-15 (N-P-K) fertilizers at a dose of 250 kg ha⁻¹. The application of plant-protection products was carried out 3 times per year using Deltamethrin (0.250 g L⁻¹), Lambda-cyhalothrin (0.250 g L⁻¹), and Boscalid + pyraclostrobin, 0.05% (0.5 kg ha⁻¹). Soil tillage was performed in autumn by plowing, with fertilizers being incorporated into a soil depth of 20–30 cm.

2.3. Sample Collection

During the harvest stage (August 2023), fruit and soil samples were collected for each management practice. To assess the morphometric attributes of plum fruits, 30 plum trees were selected, and 90 unblemished plum fruit samples were collected. The fruit samples were cleaned with ultrapure water to remove any chemicals used for pest or disease treatment and small fragments of sand and other plant components, and they were dried and stored at –20 °C before analysis.

To evaluate the soil mineral profile, from each practice and replicate, 90 samples, using a soil auger, were analyzed. The upper soil layers were carefully scraped to remove stones and plant parts. A total of 2 kg of the soil samples were collected and sieved through a 2 mm sieve after being dried, crushed, and homogenized.

Methodology of Determining Soil Chemical Parameters

For the determination of the chemical parameters of the soil, standardized methods were applied, according to protocols established by researchers in the field of soil science and chemistry. The soil pH was measured using a pH meter, following standardized procedures. The Walkley–Black method was adopted to determine the organic matter and organic carbon content in the soil. The available potassium (K) was determined by the neutral normal ammonium acetate method, with subsequent measurements being conducted by spectrophotometry [24]. The Kjeldahl method was applied for the determination of the total nitrogen [25]. Available phosphorus (P) was extracted by a 0.5 M NaHCO₃ solution at pH 8.5, with color development being determined by the ascorbic acid method. The determination of calcium (Ca) and magnesium (Mg) was performed by complexometric titration, using ammonium chloride for extraction [26].

2.4. Physical–Chemical and Phytochemical Determinations for Plum Quality Parameters

The fruit weight was determined by weighing all fruits in a sample using an analytical balance (d = 0.1 mg) and by calculating the average fruit weight (g/fruit). The assessment of flesh firmness was performed using a Qualitest HPE non-destructive penetrometer, with a 10 cm²-surface measuring device, and the results are expressed in HPE. The total soluble solids was determined using a PR-101 digital refractometer (Atago Co., Ltd., Tokyo, Japan). For the titratable acidity of the plum fruits, the titrimetric method was adopted, using phenolphthalein as an indicator, and it was then calculated by determining the amount

of NaOH consumed during titration [27]. The vitamin C content of the fruit samples was estimated by quantitative decolorization based on the 2,6-dichlorophenol-indophenol titration method. Values are expressed in mg% [28]. The total sugar content (%) was determined according to Zhang et al. [5].

The mineral content of the plum samples was analyzed using a MiniWAVE Microwave digestion system (SCP Science, Baie-d'Urfé, QC, Canada) equipped with a 50 mL Teflon dish. A 1 g homogenized sample was digested with 10 mL of HNO₃ and 1 mL of H₂O₂ in a Teflon dish at 200 °C for 20 min with a power of 1000 W. After cooling, without filtration, the resulting solution was transferred into a 25 mL volumetric flask, diluted with ultrapure water to the mark, and analyzed by atomic absorption spectrometry (ContraAA 700, Analytik, Jena, Germany) using a flame atomizer system. The values are expressed in mg/100 g of dw [29].

2.4.1. Preparation of Extracts

Reagents and Chemicals

2,2-diphenyl-1-picrylhydrazyl (DPPH), the Folin–Ciocalteu reagent, 1% citric acid, ethanol, gallic acid, sodium hydroxide, a potassium chloride solution, sodium nitrite, a sodium acetate solution, aluminum chloride, and sodium carbonate were obtained from Sigma Aldrich Steinheim (Darmstadt, Germany). All other reagents used in the experiments were of analytical grade.

Plum Powder Preparation

The fruits were at full maturity. The plum samples were washed with distilled water, and the skin and pulp were manually separated. The pulp of the fruits was freeze-dried (BIOBASE BK-FD10T equipment, Jinan, China) at −42 °C under a pressure of 0.10 mBar for 48 h up to the moisture content (MF-50 moisture analyzer, A&D Company, Tokyo, Japan) of 7%. Furthermore, the freeze-dried pulps were ground using MC 12 equipment (Stephan, Germany). The powder plum pulps were stored in zip-lock bags covered with aluminum foil at room temperature until further utilization.

Extraction of Bioactive Compounds from Plum Powders

The method employed for extracting bioactive compounds from plum powders involved the utilization of an ultrasound bath, with minor modifications [30]. A total of 1 g of plum powder was dissolved in 9 mL of 70% ethanol that was acidified with a 1% citric acid solution. The ratio of acid to solvent was 1 to 8. The samples underwent sonication using a sonication bath (Elma, Singen, Germany). This sonication process lasted for 40 min at a frequency of 40 kHz and a temperature of 25 °C. After sonication, the samples were centrifuged at 6000 rpm and 4 °C for 10 min and were filtered. The resulting supernatant was then subjected to a phytochemical analysis.

2.4.2. Extract Characterization

For the plum powder extract, the anthocyanin contents, flavonoids, polyphenols contents, and DPPH radical scavenging activities were determined.

Determination of Total Anthocyanin Content

The total anthocyanin content (TA) of the plum extract was measured using a UV–Vis spectrophotometer (Analytik Jena, Specord 210 Plus, Jena, Germany). Diluted samples (1:10) were utilized, using the pH differential method, with slight modifications [2]. The absorbance was quantified at the wavelengths of 520 and 700 nm. The TA content, expressed in mg of cyanidin-3-glucoside equivalents (C3G)/g dry weight (dw), was calculated by using the following equation:

$$\text{TA (mg C3G/g dw)} = (A \times \text{MW} \times \text{DF}) / (\epsilon \times l \times m) \quad (1)$$

where $A = (A_{520 \text{ nm}} - A_{700 \text{ nm}})$ at pH 1.0 and $(A_{520 \text{ nm}} - A_{700 \text{ nm}})$ at pH 4.5; ϵ (cyanidin-3-glucoside molar extinction coefficient) = $26,900 \text{ L mol}^{-1} \text{ cm}^{-1}$; l is the path length of the cuvette (1 cm); MW is the molecular weight of the anthocyanins = 449.2 g/mol ; DF is the dilution factor; and m is the amount of the sample.

Determination of Total Flavonoid Content

The measurement of the sample's total flavonoids was conducted using Zhang et al.'s [5] method, with slight modifications. The absorbance was quantified at a wavelength of 510 nm using a UV-Vis spectrophotometer (Analytik Jena, Specord 210 Plus, Jena, Germany). The catechin standard curve, with an R^2 value of 0.997, was utilized to determine the results, which were then reported as catechin equivalents in mg per g of dry weight (mg CE/g dw).

Determination of Total Polyphenol Content

The Folin-Ciocalteu colorimetric method was employed to quantify the total polyphenol content [5,27]. The content of polyphenolic compounds was quantified in mg of gallic acid equivalents per g of dry weight (mg GAE/g dw) using an equation derived from the standard gallic acid calibration curve, with $R^2 = 0.9837$.

Determination of Antioxidant Activity

The samples' antioxidant activity was assessed using the DPPH method [12]. A total of 100 μL of the diluted extract was combined with 3.9 mL of a DPPH solution and agitated for 30 s. After incubating for 30 min at room temperature, the absorbance at 515 nm was measured using a UV-Vis spectrophotometer (Analytik Jena, Specord 210 Plus, Jena, Germany). For the blank, 100 μL of methanol was mixed with 3.9 mL of DPPH. The results are described as μmol Trolox equivalents/g of dw using a standard curve with Trolox ($R^2 = 0.993$). The radical scavenging activity was also quantified as the percentage of inhibition using the following equation:

$$\text{DPPH scavenging activity (\%)} = (A_{\text{blank}} - A_{\text{Sample}}) / (A_{\text{blank}}) \times 100; \quad (2)$$

where A_{blank} is the absorbance at 515 nm of the DPPH solution only, and A_{sample} is the absorbance at 515 nm of the DPPH solution mixed with plum extract.

2.4.3. Colorimetric Analysis

The color parameters of the samples were evaluated using a MINOLTA Chroma Meter, model CR-410 (Konica Minolta, Osaka, Japan), equipped with a CIELAB scale. The color measurements were quantified in terms of L^* , which represents lightness (with black being $L^* = 0$ and white being $L^* = 100$); a^* , which ranges from red to green; and b^* , which ranges from yellow to blue. After calibrating the equipment using a white plate, the CIELAB color parameters were measured three times.

The hue angle (h^*) (hue angle = $180 + \arctan(b^*/a^*)$) was also determined for quadrant I ($+a^*, +b^*$), which describes the visual color appearance; the Chroma ($C^* = \sqrt{(a^*)^2 + (b^*)^2}$), which describes color intensity; and $\Delta E = (\sqrt{L^{*2} + a^{*2} + b^{*2}})$, which describes the total color difference [1,5]. The browning index (BI) and yellowness index (YI) were calculated according to the following equations:

$$\text{BI} = [100(x - 0.31)] / 0.17; \quad (3)$$

where $X = (a^* + 1.75L^*) / (5.645L^* + a^* - 0.3012b^*)$, $YI = (142.86 \times b^*) / L^*$.

2.4.4. Measuring Heavy Metals in Samples

The calibration curve's working standard solution was generated with nitric acid (HNO_3 Suprapur 65%) and stock standard solutions of Cu, Ni, Zn, and Cd (1000 mg L^{-1}).

The primary standards were diluted with 5% HNO₃ at five concentrations (0.05, 0.1, 0.2, 0.25, and 0.5 mg L⁻¹) to create the calibration curves [31]. High-purity deionized water was used in all dilutions to prevent contamination. All glass flasks were thoroughly cleaned and stored in a suitable environment to avoid contamination during the mineralization of the soil and plum fruit samples. The laboratory materials were cleaned with a warm aqueous solution (10% HNO₃), followed by a rinse with ultrapure water before the heavy metal analysis. The Cu, Ni, Zn, and Cd concentrations in the soil and fruit samples were quantified by atomic absorption spectrometry (AAS ContraAA 700, Analytik, Jena, Germany) with a flame atomization system (Table 1).

Table 1. Performance parameters for AAS analysis.

Parameters	Setting
Elements	Cu, Ni, Zn, and Cd
Relative sensitivity	100%
Measurement	Absorbance
Flame	C ₂ H ₂
C ₂ H ₂ flow rate	250 L h ⁻¹
Burner height	5–9 nm
Measurement time	3 s

2.5. Assessment of Health Risks in Orchard Plums

2.5.1. Factors of Heavy Metal Transfer (MTF)

For an understanding of the intricate interactions of soil–fruit and how they affect food safety, the MTF is calculated by the following formula [32].

$$MTF = \frac{C_f}{C_s}, \quad (4)$$

where C_f represents the metal concentration of the plum fruit (mg/kg), while C_s represents the average concentration of the metals in the soil sample (mg/kg).

2.5.2. Health Risk Assessment of Heavy Metals in Plum Consumption

The potential health risks of consuming plums contaminated with heavy metals (Zn, Cu, Ni, and Cd) were evaluated using the metal estimated daily intake (EDI), target hazard quotient (THQ), and hazard index (HI).

The EDI value of heavy metals determines the amount of metal a person is likely to ingest daily through the consumption of plum fruits in relation to their average body weight. This provides an insight into the potential health risks for both adults and children. Regulatory bodies have set permissible limits for daily consumption to avoid adverse health effects, with the limit set at less than 1 [33].

$$EDI = \frac{C_m \times I_r}{B_w}; \quad (5)$$

where I_r is the ingestion rate of fruits (0.345 kg adults⁻¹ day⁻¹ and 0.243 kg children⁻¹ day⁻¹), C_m is the value of metals in plum fruits (mg/kg), and B_w is the average body weight of adults (73 kg) and children (32.7 kg) [34].

The THQ, associated with heavy metals, is calculated by assessing the daily exposure to the reference standard oral dose (R_fD_o), which quantitatively measures the potential health risks posed by adults and children. For Zn, Cu, Ni, and Cd, the R_fD_o values are 0.3, 0.04, 0.02, and 0.0005 mg kg⁻¹ day⁻¹ [32,35].

$$THQ = \frac{EDI}{R_fD_o}; \quad (6)$$

The following standards were assumed for the interpretation of the THQ results: $THQ < 1$ = low risk, $1 < THQ < 10$ = moderate risk, and $THQ > 10$ = high risk.

The HI is calculated by adding the THQ of all toxic metals present, evaluating the non-cancer risk to human health from consuming multiple toxic metals.

$$HI = \sum_{n=1}^i THQ_{Zn} + THQ_{Cu} + THQ_{Ni} + THQ_{Cd}; \quad (7)$$

where $HI < 1$ is safe, whereas $1 < HI$ poses health risks [33].

2.6. Data Analysis

2.6.1. Analysis of Bivariate Correlation

Bivariate correlation coefficients are an essential statistical tool that enables the measurement of the strength and direction of the relationship between two variables. In the case of a multiple linear regression model, the impact of other independent variables is not taken into consideration. At the population level, this is marked by the correlation coefficient ρ_{yxj} , while at the sample level, it is represented by r_{yxj} . The values of these coefficients range from -1 to 1 , with a value of $\rho \in (-1, 1)$ indicating a perfect correlation between the variables and $\rho \in (0, 1)$ indicating a direct link. Conversely, a reverse link between the variables is indicated when $\rho \in (-1, 0)$. When $\rho \in (0)$, there is no correlation between the variables. A strong link between the variables is indicated when $|\rho| \geq 0.7$, while a moderate link between the variables is indicated when $|\rho| \in (0.4, 0.7)$. A low link between the variables is indicated when $|\rho| \in (0, 0.4)$ [23].

2.6.2. Analytical Statistics

The present study involved the conduction of triplicate analyses for each sample, and the results are reported as the mean \pm SD. SPSS for Windows (version 22.0; SPSS Inc., Chicago, IL, USA, 2007) was used for all statistical analyses. The differences between the samples were assessed by the Tukey test with the one-way analysis of variance (ANOVA) method. Pearson's method was utilized for correlation analyses (2-tailed) at $p \leq 0.05$.

3. Results and Discussion

3.1. Soil Chemical Parameters

Plum orchards are well-adapted to the soil conditions found in our country and can thrive in most soil types [36]. The most commonly used plum rootstock is *Prunus cerasifera*, which offers flexibility in terms of soil type [37]. Table 2 compares the chemical characteristics of conventionally and ecologically managed soils to determine the impact of agricultural practices on soil fertility and health. For all three varieties studied, the soil chemical properties were similar, and their values were calculated as averages per system.

The results of this study indicate neutral values, which is optimal for the genus *Prunus*, as it thrives in weakly acidic-to-neutral pH ranges (5.8 and 7.3) [38]. Soil pH is a fundamental variable influencing chemical, biological, and physical processes, as it affects nutrient availability and impacts plant growth and ecosystem productivity [39]. The analysis of nutrient concentrations showed that ecological systems have higher nitrogen (N_t) (0.206% vs. 0.178%) and lower phosphorus (P) (89.70 mg/kg vs. 98.60 mg/kg) levels compared to conventional systems. Ecological management practices enhance N retention and reduce secondary-nutrient losses, whereas conventional practices lead to greater phosphorus (P) and potassium (K) accumulations due to the use of intensive fertilizers [40,41]. These findings indicate that ecological farming practices contribute to a better organic component.

Table 2. Soil chemical parameters.

Management System	Cv	Eco
pH	7.11 ± 0.17	7.17 ± 0.11
		ns
N _t (%)	0.178 ± 0.00	0.206 ± 0.00
		*
P (mg/kg)	98.60 ± 1.88	89.70 ± 2.41
		*
K (mg/kg)	413.20 ± 14.68	406.87 ± 8.32
		ns
Ca ²⁺ sch (me/100 g sol)	13.54 ± 0.10	14.07 ± 0.25
		ns
Mg ²⁺ sch (me/100 g sol)	7.62 ± 0.22	7.84 ± 0.11
		ns
C _{org} (%)	2.04 ± 0.05	2.18 ± 0.06
		ns
Humus (%)	3.47 ± 0.11	3.68 ± 0.09
		ns

Eco—ecological, Cv—conventional, ns—nesemnificative, *—semnificative.

The soil organic matter, as indicated by C_{org} and humus percentages, is slightly higher in the ecological systems, suggesting a trend toward a better accumulation of organic matter and potentially enhancing the soil structure and ecological resilience over time. The cation levels of calcium (Ca²⁺) and magnesium (Mg²⁺) are comparable between the two systems, with no significant differences observed.

The results obtained are in agreement with other studies on increasing organic content and micronutrients in ecological systems [42–46], with higher P and K concentrations also being observed in conventional systems [47,48].

3.2. Physical–Chemical Plum Quality Parameters

The physicochemical quality parameters of the plum powders of the three varieties Tuleu Gras, Record, and Centenar, obtained by applying conventional and ecological systems, were evaluated and are shown in Figure 3.

Figure 3 shows that the soluble solids range from 15.66% to 20.53%, with significant variations between the two systems applied. The soluble solid values, which range from 15.78 to 25.30%, are consistent with those for *Prunus domestica* L., as reported in the literature [49].

Significant differences exist in the titratable acidity content, with the “Tuleu Gras” variety having the greatest values of 1.76% for the conventional system and 1.19% for the ecological system, respectively, and “Record” having only 0.62%, being the lowest. The acidity of domesticated cultivars, like *Prunus salicina* L., has been observed to range from 0.31 to 0.55% [50], is 0.9% [51], and ranges from 0.45 to 0.67% for the fruits of “Stanley” *Prunus domestica* L. grafted on *P. cerasifera* L. rootstock [52]. The total acid content of plums (*P. cerasifera* Ehrh.) from the Mediterranean region was found to vary widely, between 0.72 and 1.81% [53]. The fruit variety, level of maturity, and growing circumstances all influence the titratable acidity.

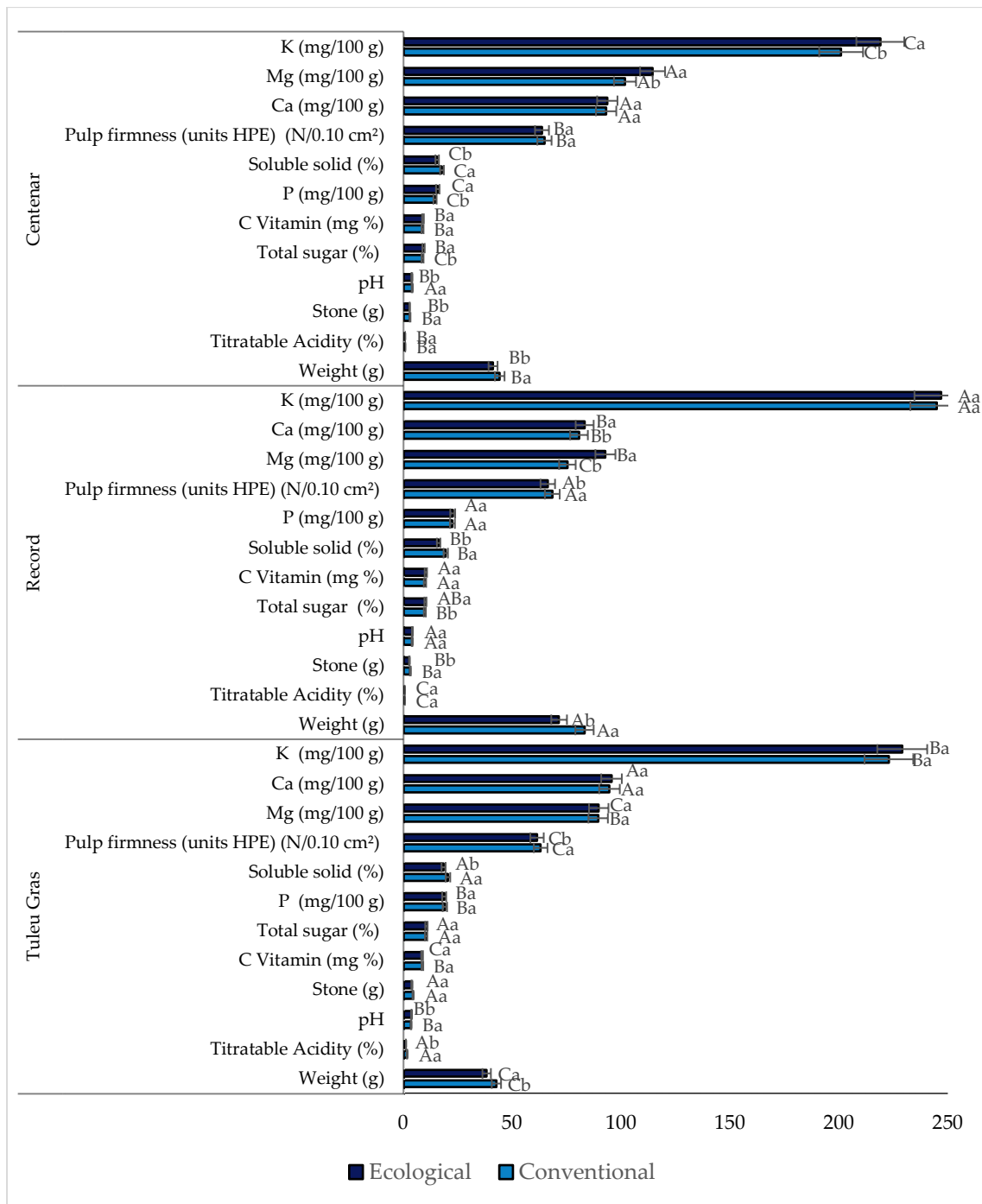


Figure 3. Physicochemical properties of three plum cultivars of powders. (Within a set of experiments, means of different plum varieties and the same system on the bars with the same color and that do not share an uppercase letter are significantly different at $p < 0.05$. Within a set of experiments, means with the same plum varieties and a different system on the bars that have different colors and that do not share a lowercase letter are significantly different at $p < 0.05$).

The preservation of foods and products depends on their titratable acidity and pH values [54]. It was discovered that there is a reversed relationship between the titratable acidity and pH value of all the samples, as indicated in Figure 3. A decrease in the acidity level is also indicative of an increase in the pH [55].

The plums' inherent physicochemical traits and ripeness may be connected to the variation in sugar content. The total sugar content was higher, at 10.72%, in the "Tuleu

Gras" cultivar and lower in the "Centenar" cultivar, at 8.92%. Overall, it was discovered that these results agree with previous findings [56,57].

The vitamin C (ascorbic acid) content in the samples was measured at 8.67–10.44 mg %, with the highest content being in the "Record" variety. Other results of the vitamin C content in wild plums (10.3 mg/100 g) are listed in the USDA food composition database [58], and that of farmed cherry plums from Turkey is 43–83 mg/100 g [52].

A fruit's firmness is not solely determined by its skin's resistance. Additionally, the pulp has an impact on it; therefore, the total firmness value is determined through the combination of both of these factors [59]. The cultivar "Record" has the greatest firmness, with a value for the maximum force of 68.48 N/0.10 cm², while "Tuleu Gras" has the least firmness, with values of 61.43 N/0.10 cm², respectively. These cultivars' hardness values may be a sign of how resistant they are to harm during post-harvest handling and transportation. Given that the fruit's main purpose is export, its high hardness value is noteworthy.

As shown in Figure 3, the mineral composition of the plum samples was dominated by the "Record" variety, which has the highest levels of potassium (K) (247.00 mg/100 g) and phosphorus (P) (22.73 mg/100 g), and "Centenar" has the highest level of magnesium (Mg) (114.54 mg/100 g), and "Tuleu Gras" has the highest level of calcium (Ca) (94.67 mg/100 g). Calcium is linked to the metabolism of vitamin D and is necessary for the normal growth of bones, teeth, and muscles. The sample "Tuleu Gras" had a high Ca concentration of 95.64 mg/100 g, which is higher than that of the wild plums from the Northern Plains of India, which have a value of 11 mg/100 g, as reported by the USDA [58].

These values are greater than the outcomes of Goosen et al. [60], who had previously reported on sourplum. While the potassium concentration found in the "Record" variety is in line with the findings obtained by Marakoğlu et al. [61], higher potassium, magnesium, and iron levels were reported by Çalışır et al. [62].

According to earlier research on the mineral profile of carob molasses by Tounsi et al. [63], K (1900 mg/100 g) dominated the mineral composition of the samples, with Ca and Mg following in the range of 360 and 270 mg/100 g, respectively. The samples of pomegranate molasses were shown to be rich in minerals, particularly in K (450–4700 mg/100 g), Ca (71.88–1803.63 mg/100 g), Mg (7.48–409.10 mg/100 g), and Fe (1.05–22.99 mg/100 g) [64].

According to Leterme et al. [65], several variables, including the fruit variety, maturity level, soil type, soil condition, climate, and irrigation system, may influence how minerals are distributed in various fruit varieties and within individual fruit parts.

Minerals are essential to many physiological processes in the human body, particularly those processes involving biosynthesis and control. Fruits and their derivatives are regarded as a good source of nutrients for diets. The United States Department of Agriculture (USDA) states that the daily recommended intake (RDA) of Ca, Mg, K, Na, Cu, Fe, Mn, and Zn is 1000–1200, 310–420, 4700, 1200–1500, 0.9, 8–14, 1.8–2.3, and 8–11 mg/day. The intake of Na and K is not to exceed 2.400 mg and 4700 mg/day, respectively [66].

3.3. Phytochemical Characterization of Plum Powders

Many research efforts show that plums contain high levels of bioactive compounds and that eating plums daily is associated with better human health. Because of their anti-inflammatory, anti-carcinogenic, antimutagenic, antioxidant, and neuroprotective properties, phenolic compounds are thought to have the greatest positive effects on human health [67]. Figure 4 summarizes the results of the phytochemical characterization of the plum powder varieties.

Anthocyanins, compounds that are prevalent in many fruits, especially plums, were found at their highest levels in the "Tuleu Gras" variety. The "Record" variety exhibited the highest concentrations of total polyphenols (7.76 mg GAE/g) and flavonoids (3.65 mg CE/g dw), significantly surpassing other varieties in both cultivation systems. Additionally, the "Record" variety demonstrated the greatest antioxidant activity (25.54 µM Trolox/g dw, 97.07%), with significant differences between the systems.

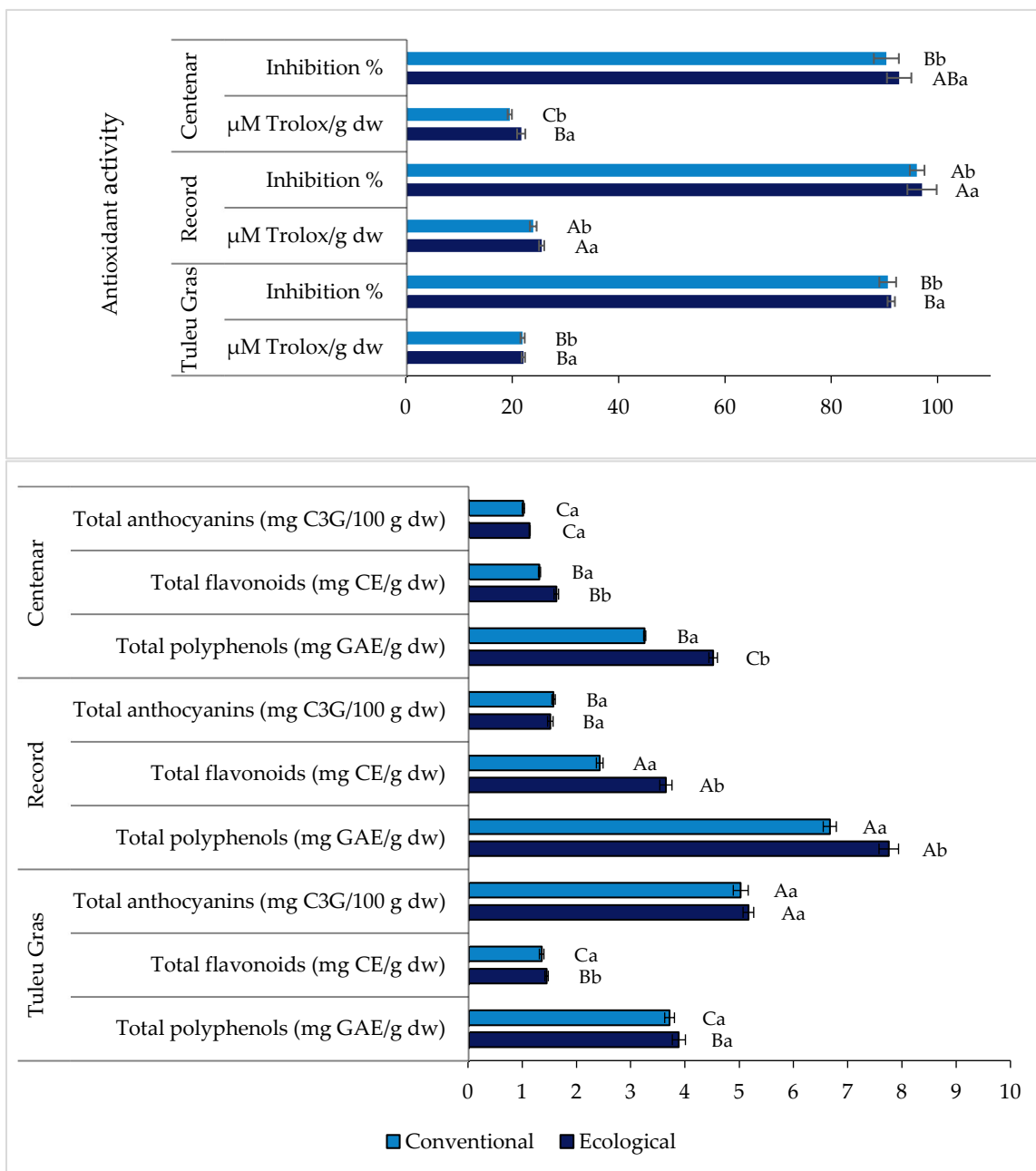


Figure 4. Characterization of the phytochemicals of plum powders. (Within a set of experiments, means of different plum varieties and with the same system on the bars with the same color and that do not share a uppercase letter are significantly different at $p < 0.05$. Within a set of experiments, means of the same plum varieties and with a different system on the bars that have a different color and that do not share a lowercase letter are significantly different at $p < 0.05$).

Our reported data are in agreement with other studies. Previous research studies have shown that the contents of polyphenols in plum range from 186.4 mg to 391.2 mg GAE/100 g of fresh weight [68]. Fruits of the plum ‘Stanley’ had a high content of polyphenolic compounds (70 to 214 mg GAE/100 g) [69]. The characteristic polyphenolic compounds of plums (86% of total polyphenolic compounds) are neochlorogenic (3-O-caffeoylquinic) and chlorogenic (3-O-caffeoylquinic) acids [17].

In studies conducted with different plum genotypes, the total phenolic content varied from 754.0 (‘Fortune’) to 983.3 (‘Friar’) mg GAE/kg. The total flavonoid content varied

from 312.3 ('Fortune') to 488.0 ('Fortune') mg CE/kg, and the antioxidant activity ranged from 72.6% ('Fortune') to 79.3% ('Friar'), respectively [69].

Mehta et al. [70] reported a total phenolic content of dried plum of a 1.05 mg GAE/100 mg extract and a total flavonoid content of a 0.583 mg CE/100 mg extract for dried plums (*Prunus domestica*), which were obtained at 40 °C and 140 rpm for 24 h. In another study, the yields of the total anthocyanin content, total phenolic content, and total flavonoids were 649.47 mg CE/100 g, 2266.36 mg GAE/100 g, and 1668.43 mg Quercetin Equivalent/100 g, respectively, which were obtained with optimized parameters, including the ultrasound power (366.25 W), extraction temperature (37.61 °C), extraction time (47.48 min), and ethanol concentration (70%) [71].

Cevallos-Casals et al. [11] documented the significant antioxidant capacity of fourteen red-flesh plum genotypes. The antioxidant capacity values obtained from the reaction of extracts with the free radical DPPH• (2,2-diphenyl-1-picrylhydrazyl) ranged from 1254 to 3244 µg Trolox/g of fresh weight. Using the DPPH technique, antioxidant activity levels were shown to be between 15 and 65% [7] and 49.10 and 87.94% [72].

The genetic heterogeneity among different plants leads to changes in the biosynthesis of phenolic secondary metabolites, resulting in significant disparities in the total phenolic and antioxidant activities throughout the commercial ripening stage [73,74].

Although the genotype is thought to be the primary cause of these differences, other factors such as the climate and soil characteristics, geographical position, crop type and harvest time, crop storage or processing, method, or recurring variations in applied cultural practices also significantly affect the phytochemical composition of fruits [75,76].

3.4. Color Evaluation of Plum Powders

Fruits of *Prunus domestica* vary greatly in terms of size, shape, color, and flavor. The colors of plum fruits range greatly from one another. The fruit ripening of *Prunus domestica* cultivars exhibits significant heterogeneity in terms of anthocyanins and chromatic characteristics [77].

The results of the plum powder color measurements (L^* , a^* , and b^* and the parameters ΔE , C^* , h^* , BI, and YI) are revealed in Table 3. The L^* values, which show the lightness of the samples, ranged from 52.21 (Tuleu Gras) to 56.89 (Record). The "Record" variety showed the highest luminosity.

Table 3. Colorimetric parameters of plum powders.

Varieties	Management System	L^*	a^*	b^*	ΔE (Total Color Difference)	C^* (Chroma)	h^* (°) Dual Color Appearance (Hue Angle)	BI	YI
Tuleu Gras	Eco	53.36 ± 0.80 Ca	10.27 ± 0.08 Aa	16.47 ± 0.52 Ba	56.78 ± 1.08 Ca	19.41 ± 0.28 Ba	1.01 ± 0.03 Aa	50.46 ± 1.35 Ba	44.09 ± 1.08 Ba
	Cv	52.21 ± 0.95 Cb	9.14 ± 0.16 Ab	15.33 ± 0.37 Bb	55.17 ± 1.48 Bb	17.85 ± 0.44 Bb	1.03 ± 0.02 Aa	47.06 ± 1.67 Bb	41.95 ± 1.09 Bb
Record	Eco	56.89 ± 1.08 Aa	8.33 ± 0.24 Ca	11.34 ± 0.26 Ca	58.94 ± 2.09 Ba	14.08 ± 0.37 Ca	0.94 ± 0.02 Aa	32.54 ± 0.67 Ca	28.48 ± 0.89 Ca
	Cv	56.49 ± 1.52 Aa	7.56 ± 0.11 Cb	10.86 ± 0.19 Cb	58.03 ± 1.19 Aa	13.23 ± 0.42 Ca	0.96 ± 0.01 Aa	30.75 ± 0.23 Cb	27.46 ± 0.67 Ca
Centenar	Eco	54.15 ± 1.92 Ba	9.26 ± 0.23 Ba	26.14 ± 0.46 Aa	60.83 ± 0.46 Aa	27.73 ± 0.67 Aa	1.23 ± 0.03 Aa	76.70 ± 1.34 Aa	68.96 ± 1.57 Aa
	Cv	53.48 ± 1.09 Bb	8.67 ± 0.22 Bb	25.02 ± 0.13 Ab	59.68 ± 1.04 Aa	26.49 ± 0.60 Ab	1.24 ± 0.02 Aa	70.58 ± 2.00 Ab	66.83 ± 1.15 Ab

Within a set of experiments, means of different plum varieties and with the same system on the same column that do not share an uppercase letter are significantly different at $p < 0.05$. Within a set of experiments, means of the same plum varieties and with a different system on the same column that do not share a lowercase letter are significantly different at $p < 0.05$.

According to the values of the color parameters, the fruit powder of the "Tuleu Gras" variety had the darkest pulp tone, with the highest ratio of red, which is most likely related to the pulp's highest anthocyanin content. The higher anthocyanin content of the "Tuleu Gras" plum variety, which exhibited the highest value of the color parameter a^* among the plum samples, can be explained [78]. The positive value of the parameter a^* indicates the tendency to display a red color. Similar findings were reported for this fruit color in plums (*Prunus domestica* L.) of three cultivars: "Węgierka Zwykła", "Bluefre", and "Elena" [79].

However, as some authors do not define their measurement methods, such research may be considered inaccurate when comparing color measurements with data from the literature.

The b^* parameter represents the blue-to-yellow intensity; a positive value indicates a trend towards yellow shades in plum powders. Chroma indicated that the red hue was the most expressive in determining the powders' color, following the trend of the parameter a^* . As 0 and 360 angles are associated with red, the hue angle was placed in the first quadrant of the color solid to represent the redness of all samples. The total color difference was between 55.17 and 60.83. The yellowness index (YI) and browning index (BI), which show the purity of the brown color, were obtained using the L^* , a^* , and b^* values. YI is associated with processing and light exposure-induced product degradation. The highest YI and BI values were identified for the "Centenar" plum variety samples and could be attributed to Maillard reactions or pigment releases.

All of the data were positioned in the first quadrant ($+a^*$, $+b^*$) based on the results for the values of a^* and b^* , indicating anthocyanins' propensity for yellow and red hues.

3.5. Pearson Correlation Analysis of Plum Fruit Characteristics

A Pearson correlation analysis was conducted to assess the correlation between the phytochemical composition and colorimetric parameters in plum powders, as shown in Table 4. This analysis revealed a significant positive correlation at the 0.01 level between the L^* values and antioxidant activity, polyphenols, and flavonoids, with correlation coefficients of 0.992, 0.969, and 0.897, respectively. A similar strong correlation was observed between the antioxidant activity and polyphenols ($r = 0.989$) as well as between the polyphenols and flavonoids ($r = 0.967$). Additionally, a significant positive correlation was found between the flavonoids and oxidative activity ($r = 0.927$). Overall, these findings suggest a strong correlation between these characteristics in the analyzed samples.

Table 4. Pearson correlation analyses between phytochemical composition and colorimetric parameters in plum powders.

Pearson Correlation	L^*	a^*	b^*	AA (Inhibition %)	TP	TF	TA
L^*	1						
a^*	−0.705	1					
b^*	−0.527	0.390	1				
(AA) (Inhibition %)	0.992 **	−0.809	−0.515	1			
TP	0.969 **	−0.790	−0.586	0.989 **	1		
TF	0.897 *	−0.651	−0.570	0.927 *	0.967 **	1	
TA	−0.781	0.669	−0.100	−0.781	−0.711	−0.615	1

AA—antioxidant activity; TP—total polyphenols; TF—total flavonoids; TA—total anthocyanins; **, correlation is significant at the 0.01 level (2-tailed); *, correlation is significant at the 0.05 level (2-tailed).

3.6. Concentrations of Heavy Metals in Orchard Plums

Figure 5 shows the results of a comparative analysis between conventional and ecological soil management systems that was carried out, taking into account the levels of heavy metals in soils and fruits and comparing them with the safety threshold values set in the legislation.

In the conventional soil, higher concentrations of Zn, Ni, and Cd were observed compared to the ecological system. However, the Cu concentrations were higher in the ecological soil, reaching 119.96 mg/kg, which is slightly above the 100 mg/kg safety limit. The Zn, Ni, and Cd concentrations followed this trend, with values of 63.43 > 27.23 > 0.41 (mg/kg) in the conventional soil and 50.07 > 13.43 > 0.91 (mg/kg) in the ecological soil. These findings indicate a potentially better efficiency of the ecological system in maintaining heavy metal concentrations within safe limits, although the Cu levels in both systems raise potential concerns.

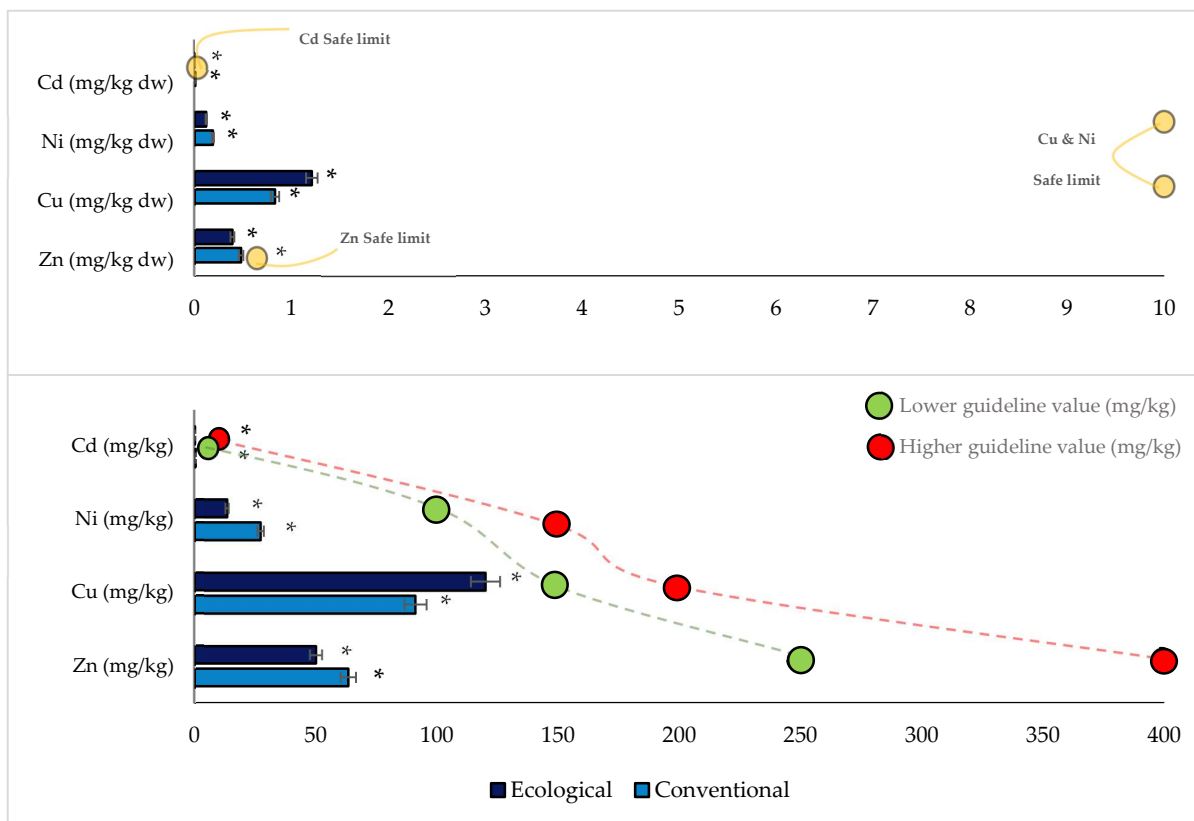


Figure 5. Mean concentrations of heavy metals in plum orchard (*— $p < 0.05$, WHO/FAO, 2023. The guideline values were defined on the basis of ecological risks).

Research has shown that the copper concentration in ecological orchards is generally higher than in conventionally grown orchards. The results of Fu [39] show that the long-term application of copper-containing fungicides resulted in a 3.5-fold increase in the copper concentration in orchard soils (85.77 mg kg^{-1}) compared to the background value (24.0 mg kg^{-1}) in nearby agricultural soils. A study in Northern Macedonia found that vineyard soils used in ecological agriculture had significantly higher available copper concentrations than control samples from nearby forests and sites [80]. Also, a study conducted by Jez et al. [81] showed higher concentrations of copper in an ecologically grown vineyard soil than in conventional soils.

However, another study of olive production in Turkey found that reduced copper applications in ecological management resulted in a 50% reduction in the soil copper content, highlighting the idea that ecological practices can help mitigate copper accumulation in the soil [82]. Overall, although there is some evidence of higher copper concentrations in ecological orchards, the magnitude of this difference may vary depending on specific farming practices and existing environmental conditions.

The higher copper concentrations in the ecological orchards compared to conventional orchards can be attributed to the widespread use of copper-based fungicides in ecological agriculture [81–83]. The annual limit of copper used in ecological agriculture is only sometimes respected, leading to higher soil concentrations. Besides this, the addition of ecological soil amendments, such as vermicompost tea, can increase the soil copper content [84]. These factors contribute to the higher copper concentration in ecological orchards compared to conventional orchards. To reduce copper accumulation in soil and crops, further research is needed to explore alternatives to copper-based fungicides in ecological agriculture. Fu et al. [39] point out that using natural fertilizers and soil management methods specific to ecological agriculture contributes to copper accumulation

in the soil. This can be explained by the exclusive use of ecological fertilizers, which, in the long term, leads to an increase in the concentration of this element in the soil.

However, it is important to note that these findings are not consistent across studies. Other research on vineyard soils in Italy has also noticed consistent trends regarding the copper behavior between conventional and ecological management systems [82]. Therefore, further research is needed to fully understand the relationship between copper concentrations and ecological vs. conventional orchards.

Regarding the metals in the sampled fruits, the trend was $\text{Cu} > \text{Zn} > \text{Ni} > \text{Cd}$, with values in the conventional system being $0.83 > 0.48 > 0.19 > 0.009$ (mg/kg) and those in the ecological system being $1.21 > 0.39 > 0.12 > 0.006$ (mg/kg).

The concentrations of these metals in fruits have been the subject of numerous studies. It was observed that the results obtained are lower compared to other published results. Radwan and Salama [85] and Onianwa et al. [86] reported Cu concentrations between 1.22 and 2.13 mg/kg, 1.27 and 2.13 mg/kg, and 2.51 and 0.95 mg/kg for watermelons, oranges, and bananas, respectively. They also reported Zn levels between 5.35 and 7.40 mg/kg, 2.38 and 2.20 mg/kg, and 5.59 and 1.50 mg/kg for the same fruits.

In another study, the total concentrations of 13 metal elements were determined in the fruits and leaves of three tree species from San Luis Potosi, Mexico. The study showed that the contents of Zn (20.37 mg kg^{-1}), Cu (3.34 mg kg^{-1}), Ni (0.577 mg kg^{-1}), and Cd (0.15 mg kg^{-1}) in the fruits of three species were within the phytotoxic ranges, with higher values than those in the present study [87]. In another study, the accumulation of toxic elements in various vegetables, including *Prunus armeniaca*, was analyzed, and it was found that the Cu, Zn, and Cd concentrations for apricot kernel peels (18.59, 1.6, and 0.059 mg/kg) were higher than those in Apricot kernels (16.19 mg/kg, 1.3, 0.06) with a whole fruit value of 17.94 of Cu, 2 of Zn and 0.058 of Cd. In the case of Cd, it exceeded the maximum allowable concentration (0.2 mg/kg FAO/WHO 2021) [88]. Also, in a study conducted in Nigeria, the metal concentrations in fresh fruits and vegetables were ND-0.91, ND-1.12, 0.74–1.51, 0.27–1.83, 0.02–1.74, and 0.15–1.93 (mg/kg) for Cd, Cu, Ni, Mn, Zn, and Pb, respectively [89].

Finally, another study analyzed the concentration of some heavy metals in vegetable fruits (tomatoes, cucumbers, and watermelons) using atomic absorption spectrophotometry (AAS). Higher concentrations were found for Zn compared to our results, lower values for Cu, and values exceeding the maximum allowable limit for Cd [90].

Therefore, analyses in recent years show a consistent trend of higher copper concentrations in ecological orchards compared to conventionally grown orchards. System-specific farming practices and long-term impacts on soils and plants drive this difference.

3.7. Pearson Correlation Analysis of Heavy Metals in Plum Orchard

The study of the heavy metal concentrations in the soil of the plum orchards is essential for assessing the potential impact of pollution on the soil's health and, thus, on the horticultural production in this region. Table 5 shows the results of the Pearson analysis, highlighting the correlation coefficient between the concentrations of different heavy metals in the soil.

Table 5. The correlations of metal content in the plum orchard.

Pearson Correlation	Zn (mg/kg)	Cu (mg/kg)	Ni (mg/kg)	Cd (mg/kg)
Zn (mg/kg)	1			
Cu (mg/kg)	0.887 **	1		
Ni (mg/kg)	0.982 **	0.873 **	1	
Cd (mg/kg)	0.913 **	0.786 *	0.961 **	1

** , correlation is significant at the 0.01 level (2-tailed); * , correlation is significant at the 0.05 level (2-tailed).

Based on the data, moderate-to-very strong positive correlations were found: Cu–Cd ($r = 0.786$), Zn–Cu ($r = 0.887$), Zn–Cd ($r = 0.913$), Cu–Ni ($r = 0.873$), Zn–Ni ($r = 0.982$),

and Ni–Cd ($r = 0.961$). In another study, a positive correlation was determined between Cd–Cu (0.35) and Cu–Zn (0.67) in peach orchards. The strong correlations found between these heavy metals suggest that they share the same origin or are interdependent [91]. Understanding this correlation is essential for implementing environmental protection measures and proper soil management to maintain ecosystem health and ensure sustainable horticultural production in the future [92].

The relationship between soil heavy metal contents and conventional vs. ecological fruits is presented in Table 6. The analysis revealed a very strong positive correlation between the heavy metal content in the conventionally managed soil and the conventional fruit ($r = 0.991$). Similarly, there is a very strong positive correlation between the heavy metal content in the soil under the ecological system and with the ecological fruit ($r = 0.995$). These findings indicate a link between soil heavy metal contents and their presence in fruits.

Table 6. The correlation between the fruits and soil system.

Pearson Correlation	Soil Cv	Soil Eco	Fruit Cv	Fruit Eco
Soil Cv	1			
Soil Eco	0.951 *	1		
Fruit Cv	0.705	0.479	1	
Fruit Eco	0.918	0.995 **	0.963 *	1

** , correlation is significant at the 0.01 level (2-tailed); * , correlation is significant at the 0.05 level (2-tailed).

Metal Transfer Factor

Figure 6 shows the transfer of heavy metals from the soil to the fruit (Zn, Cu, Ni, and Cd) that were analyzed in conventional and ecological horticultural practices, and it highlights the importance of monitoring this phenomenon to ensure soil quality and food safety.

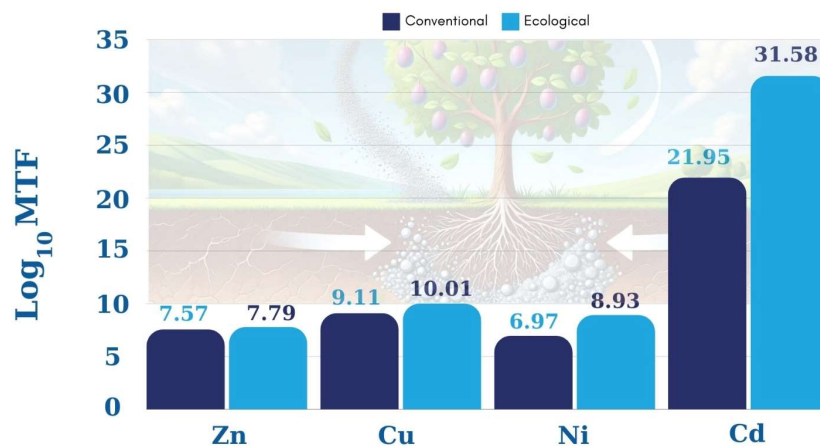


Figure 6. Metal transfer factor (Log₁₀) from soils to fruit of *Prunus domestica* L.

The translocation of metals in the fruit was within permissible risk limits (≤ 1), and the mean values of the selected metals differed between the cropping systems. In the conventional system, the mean metal translocation factor (MTF) followed the order of Ni < Zn < Cu < Cd, whereas in the ecological system, it was Zn < Ni < Cu < Cd. Thus, horticultural practices, whether conventional or ecological, impact the transfer of heavy metals into fruits, as shown in Figure 6. The MTF from soils to fruits has been investigated in several studies. Nitu et al. [93] studied the accumulation and transfer coefficient of heavy metals in blueberry and raspberry fruits. The authors concluded that all concentrations of Cu and Zn presented a low risk for human consumption. Pruteanu et al. [94] examined Cu accumulation and transference from soils to vegetables and fruits. The authors showed the presence of copper in the soils and its accumulation in the vegetative parts of vegetables and fruits consumed by humans. Waida et al. [95] investigated different edible plants

and the transfer factor for different metals. They found that the values differed slightly between the geographic areas studied. The authors concluded that water and edible plants in the study area were good for public consumption. Sousa et al. [96] assessed Cd and Zn contamination in soils and found that Zn translocation in *Solanum lycopersicum* was associated with ecological use.

3.8. Assessment of Health Risks of Metals in Plum Fruits

The daily uptake of trace metals for children and adults in our sample is presented in Table 7.

Table 7. Evaluated EDI, THQ, and HI of metals in plum fruit samples.

Management System	Heavy Metals	Children			Adults		
		EDI (mg/kg/Day)	THQ (mg/kg/Day)	HI = \sum THQ	EDI (mg/kg/Day)	THQ (mg/kg/Day)	HI = \sum THQ
Cv	Zn	3.57×10^{-3}	1.19×10^{-2}	3.71×10^{-1}	2.27×10^{-3}	7.56×10^{-3}	2.35×10^{-1}
	Cu	6.17×10^{-3}	1.54×10^{-1}		3.92×10^{-3}	9.80×10^{-2}	
	Ni	1.41×10^{-3}	7.05×10^{-2}		8.90×10^{-4}	4.45×10^{-2}	
	Cd	6.74×10^{-5}	1.35×10^{-1}		4.49×10^{-5}	8.51×10^{-2}	
Eco	Zn	2.89×10^{-3}	9.63×10^{-3}	3.69×10^{-1}	1.84×10^{-3}	6.13×10^{-3}	2.31×10^{-1}
	Cu	8.99×10^{-3}	2.25×10^{-1}		5.72×10^{-3}	1.43×10^{-1}	
	Ni	8.90×10^{-4}	4.45×10^{-2}		5.10×10^{-4}	2.55×10^{-2}	
	Cd	4.25×10^{-5}	8.99×10^{-2}		2.84×10^{-5}	5.67×10^{-3}	

This study found that the EDI values for the accumulated elements in the plums exhibited the same trend for both children and adults, with the order being Cu > Zn > Ni > Cd. A comparative analysis showed that Cu had the highest EDI value in both ecological (8.99×10^{-3}) and conventional (6.17×10^{-3}) systems. Among all the elements, Cd had the lowest EDI values for both adults and children, with its value in the ecological system (2.84×10^{-5}) being lower than in the conventional system.

In a study of mango fruits, the EDI values for Zn, Cu, and Cd were lower in adults than in the present study, ranging from 1.1×10^{-4} to 2.83×10^{-4} and from 1.56×10^{-5} to 1.75×10^{-4} and were ND- 1.7×10^{-4} mg/kg/day, respectively. In various studied samples (grapes, apples, mangoes, and figs) the EDI value of Cd ranged from 0.525 to 3.96 mg/kg⁻¹, and the concentration of Ni ranged from 1.04 to 4.66 mg/kg⁻¹. The hazard index (HI) for these metals was higher than 1, indicating desirable effects on human health [97]. The values for Cu and Zn were 0.0015–0.012 and 0.026–0.421 mg/kg/day, respectively, which are higher than those in the present study [98].

The THQ through fruit consumption is a real indicator of the presence of chemical pollutants. Although it cannot provide an accurate risk assessment, the THQ specifies an alert level [99]. In this research, the THQ for all metals was <1, indicating that metal intake through plum fruit consumption does not pose a health risk to the population in the study area.

The highest THQ value was recorded for Cu in children in the ecological system (2.25×10^{-1}), followed by the conventional system (1.54×10^{-1}). The lowest THQ value was calculated for Zn, ranging from 9.63×10^{-3} to 1.19×10^{-2} .

According to the results in Table 7, the THQ values for Cd are lower than those reported in the literature for the South Ethiopian region [35], where Cd values of 3.16×10^{-1} and 3.4×10^{-1} were reported for adults. Lower Cd values have also been reported in Egypt, with estimated values for Cd being between 0.672432 and 1.267432 [98].

The hazard index (HI) of trace metals in this study ranged from 3.71×10^{-1} to 2.31×10^{-1} , which is lower than those reported in Egypt [98], where the HI ranged

from 0.912073 to 1.644178. In another study focusing on mango fruits, the HI of metal traces ranged from 7.44×10^{-3} to 3.49×10^{-1} , indicating an acceptable level of non-carcinogenicity below the reference unit.

4. Conclusions

The findings of this study demonstrate that the quality attributes of plum fruits grown in the northeastern region of Romania exhibit significant variations depending on the tillage management practices employed. Plums are an excellent source of natural antioxidants and bioactive compounds, such as polyphenols, flavonoids, anthocyanins, and vitamin C. The growing consumer interest in plums is largely attributed to their perceived valuable nutritional properties, coupled with the increasing global demand for ecological fruit products.

The results indicate that the variations in total polyphenols and anthocyanins are highly dependent on both the cultivar and the tillage management practices. Specifically, the “Tuleu Gras” variety recorded the highest level of total anthocyanins, while the “Record” variety excelled with a superior content of total polyphenols, flavonoids, and antioxidant capacity compared to the other two cultivars. Additionally, the “Record” variety exhibited the highest antioxidant activity and vitamin C levels, followed by the “Centenar” variety, particularly under ecological management systems.

This study underscores the importance of understanding the relationship between the antioxidant activity and heavy metals of plum fruits in promoting human health. Heavy metal concentrations in the soil and plum fruits ($\text{Cu} > \text{Zn} > \text{Ni} > \text{Cd}$) were below the maximum guidelines set by the World Health Organization (WHO); our findings confirm that the THQ and HI values for these metals in plum fruits indicate no adverse effects on human health from the consumption of these fruits in the study area.

The study’s findings have significant implications for regulatory bodies and governmental agencies. The necessity for the ongoing regulatory monitoring of heavy metal levels in plum production areas is emphasized to ensure the continued provision of safe, healthy food. The insights provided by this study are essential for these entities in developing preventive strategies to minimize heavy metal pollution and to facilitate comparisons of plum quality across different production regions globally. Therefore, these findings emphasize the need for sustainable crop management and horticultural practices to safeguard environmental integrity and consumer health.

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