



Article

Physico-chemical and phytochemical properties of selected plum varieties in conventional and ecological system: Analysis of antioxidant potential, impact of heavy metals and health risks →

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Abstract: Due to their potential health benefits, plums (*Prunus domestica* L.), well-known for their nutritional content and diverse phytochemical composition, have become the subject of intense research interest. The physico-chemical and phytochemical characteristics of three plum varieties—Tuleu Gras, Record, and Centenar—cultivated in both conventional and ecological systems are examined in this work. The emphasis is on their capacity as antioxidants, the existence of heavy metals, and how they affect the health of adults and children (EDI, THQ, and HI). In order to measure essential parameters like fruit firmness, soluble solid content, titratable acidity, total sugar, thanoid compounds, C vitamin, P, K, Ca, Mg, color, and particular phytochemicals like flavonoids, anthocyanins, and phenolic compounds, a wide range of analytical techniques is used in the research. Using a combination of analytical methods, namely UV/Vis spectrophotometry and atomic absorption spectrometry, the study assessed the phytochemical composition of plum extract and the quantity of heavy metals (Zn, Cu, Ni, and Cd). This study aims to demonstrate the nutritional value of plums while underscoring the need to monitor heavy metal pollution during the plum growing process to safeguard public health. →

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

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1. Introduction

Plum fruits (*Prunus domestica* L.), belonging to the *Prunus* genus, subgenus *Prunus*, family *Rosaceae*, have long been celebrated for their succulent taste and potential health benefits [1, 2]. Humans have cultivated these for centuries and are a staple in the global fruit market [3]. 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 [4]. Plums are versatile and can be enjoyed fresh, dried, canned, or used for brandy production [5].

As consumers increasingly prioritize their food's flavor and nutritional content, understanding the quality parameters, heavy metal content, and antioxidant activity of plum fruits has become pivotal. Quality parameters encompass a spectrum of attributes, ranging from physical characteristics such as color, size and texture to intrinsic factors like heavy metals content, sugar content, acidity, and aroma [6, 7].

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 can 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 fruit stands out as an important ally in the fight against oxidative stress [8-10].

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 fruit can be understood through the mechanism of action of antioxidants. When enter the body, heavy metals can generate free radicals, reactive oxygen or nitrogen species, damaging DNA, proteins and cell lipids. The antioxidants in plum fruit act as protective shields, neutralizing these free radicals and thus preventing cell damage [11].

Studies have shown that regular consumption of plum fruit can help reduce heavy metal levels in the body, with a detoxifying effect. 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. Plums are particularly beneficial for cardiovascular health due to their high fiber and potassium content and ability to reduce cholesterol levels [9,10]. Other research has shown that these bioactive compounds, such as polyphenols, flavonoids, anthocyanins, and vitamin C, exhibit notable antioxidant potential [12], have numerous health benefits, such as anti-proliferative activity against breast cancer, immune-boosting properties, hypoglycemic effects, and mitigation of age-related cognitive decline, including also and anticancer properties [13-16].

Analyzing the quality parameters of plum fruits involves a comprehensive evaluation of their visual appeal, firmness, and freshness. 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 [17].

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 [18, 19]. The goal is to identify plum types high in antioxidants, which could potentially positively impacts on 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 comparing to fruits such as oranges, apples, and strawberries [20, 21]. 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 [22].

In summary, the relationship between heavy metals and the antioxidant activity of plum fruit is essential for maintaining human health when enfronting to environmental challenges. Integrating these fruits into the daily diet can significantly protect the body against the harmful effects of heavy metals and promote overall health.

This study evaluates the physico-chemical quality parameters, phytochemical characteristics, heavy metal concentrations, and antioxidant activity in plum fruits grown under different management systems. This research provides important insights into the nutritional value and safety of plum fruits for human consumption.



2. Materials and Methods

2.1. Research Area Description

„Adamachi” Farm, located in the northeast Romania on the Moldavian Plateau (47°15' N-27°30' E), is part of Iasi University of Life Sciences. ~~“Adamachi” Farm, part of~~

the University of Life Sciences of Iasi, is located in north-eastern Romania, on the Moldavian Plateau (47°15' N, 27°30' E). This experimental area is characterized by a humid temperate-subtropical climate, according to the Köppen-Geiger classification, which provides optimal conditions for the cultivation of fruit trees (<https://climateknowledgeportal.worldbank.org/country/romania>, accessed on 25 April 2024). The climate of the region is characterized by warm summers and moderate winters, with an average annual temperature of 10°C and annual precipitation of about 518 mm. The environmental conditions during this period are represented in Figure 1 and Figure 2 (<https://www.fieldclimate.com>, accessed on 1 May 2024).

The plum orchard (*Prunus domestica* L.) was established in 2014. The varieties studied ('Tuleu Graș', 'Centenar' and 'Record') are located in an area with aric-cambic chernozem the type of soil with a loamy-clay texture. The soil is fertile, well-drained, and rich in nutrients, which helps in producing high-quality fruits. The soil also has a humus content of 4.05% and a cationic exchange capacity of 19.03 me/100g soil [23].

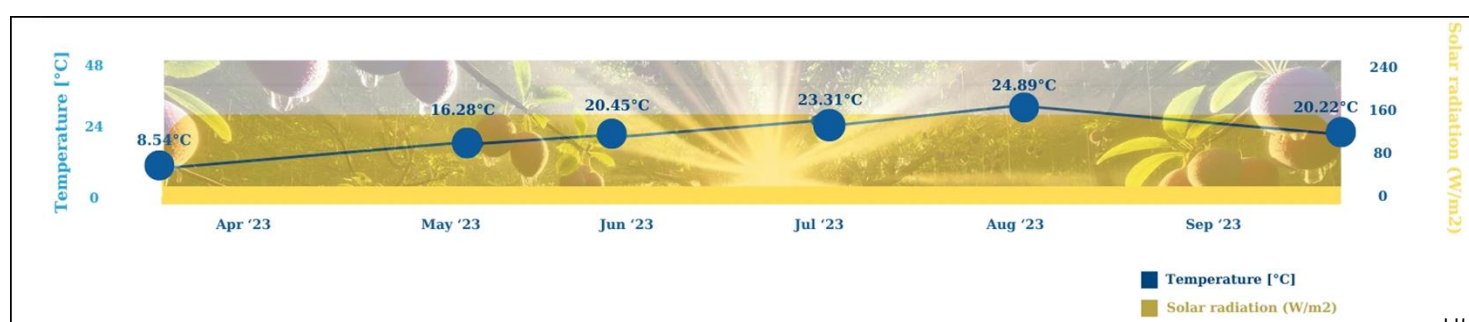


Figure 1. The monthly variations in temperature (°C) and solar irradiance (W/m²) throughout the growth period.

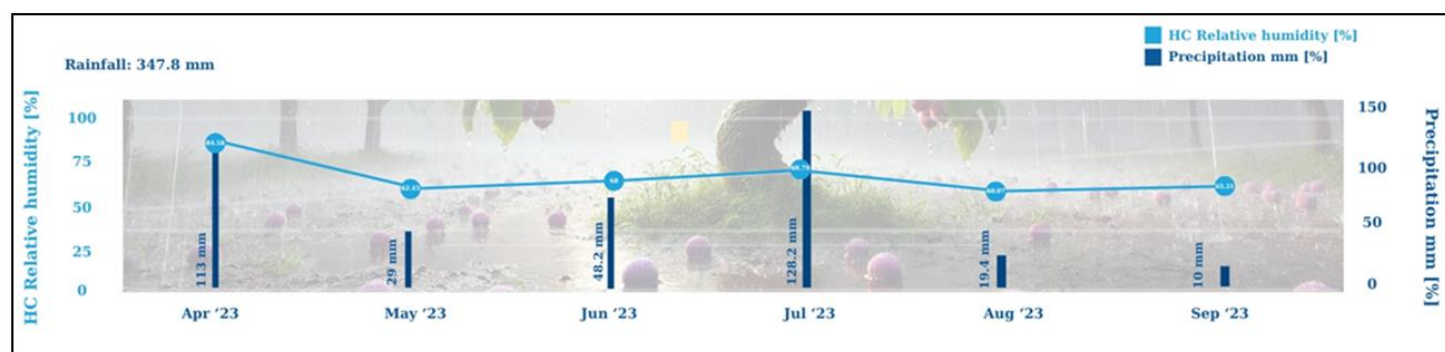


Figure 2. The precipitation (mm) and relative humidity (%) during the growth period.

2.2. Sample collection

An area of 5500 m² was divided into plots with 5m wide buffer strips to research the ecological (Eco) and conventional (Cv) management of plum orchards. The plots were positioned 200m apart to avoid interference from synthetic inputs. The research involved three replicates, each comprising 31 trees. Three sampling areas with five points each were designated for each orchard plot.

In August 2023, soil and mature fruit samples were collected from the orchard. The samples were combined to form composite samples and then placed in polyethylene bags. To collect 90 soil samples, a polyethylene shovel and hand drill were used. The soil samples were carefully scraped to remove stones and plant parts, and after harvesting 500 g of soil, the sample average was determined. Soil samples were dried, crushed, and homogenized. The samples were then sieved through a 2 mm sieve.

Ninety fruits were collected from each system, sorted immediately, and washed with distilled water to remove any chemicals used for pest or disease treatment, as well as small fragments of sand and other plant components. The physico-chemical properties of the fruits were measured before storing them at -20°C.

2.3. Physical-chemical and phytochemical determinations for plum quality parameters

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) [24].

The assessment of flesh firmness was performed using a Qualitest HPE non-destructive penetrometer with a 10 cm² surface measuring device, and the results were expressed in HPE. Soluble ~~dry~~^{Solids} matter was determined using a PR-101 digital refractometer.

~~Titratable acidity:~~ For the titratable acidity of plum fruit, the titrimetric method ~~measured total acidity~~ using phenolphthalein as an indicator. This involved 20 g of homogenized fruit mixed with 250 ml of deionized water, then filtered using filter paper. 20 mL of filtrate was titrated with a 0.1 mol/L sodium hydroxide solution to a red color shift [25]. Titratable acidity is then calculated by determining the amount of NaOH consumed during titration [26].

~~Vitamin C content (mg %):~~ The vitamin C content of fruit samples was estimated by quantitative decolorization based on 2,6-dichlorophenol-indophenol titration method [27]. Values were expressed in mg%.

Thanoid substances were determined by Lawenthal Meubeur method. Indigo-carmin was used as an indicator during the process [28].

To estimate the total sugar content, 25 ml of juice was taken from the fresh fruit in a 100 ml flask. Additionally, 5 ml of concentrated hydrochloric acid and 20 ml of distilled water were added to convert non-reducing sugars into reducing sugars. This mixture was left at normal room temperature for 24 hours for complete hydrolysis and then neutralized with 1 N NaOH solution using phenolphthalein as an indicator. Finally, the volume was made up to 100 ml with distilled water. The resulting solution was titrated against 10 ml Fehling's solutions to estimate the total sugars [29]. The total sugar content was calculated using the following formula:

$$\text{Total sugars} = 25 \times \frac{X}{Z} \quad (1)$$

where, X – volume (ml) of standard sugar used against 10 ml of Fehling's solution; Z – volume (ml) of sample aliquot titrated against 10 ml of Fehling's solution.

Determination of mineral content analysis (K, P, Ca, Mg) was carried out after acid digestion of samples [30].

2.3.1. Preparation of extracts

2.3.1.1. Reagents and Chemicals

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

2.3.1.2. Plum extract (PE) 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 93% dry weight. Further, 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.

2.3.1.3. Extraction of Bioactive Compounds from plum powders

The method employed for extracting bioactive compounds from plum powders involved the utilization of ultrasound, with minor modifications [31]. 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 an Elmasonic S 180 H sonication bath from (Elma, Singen, Germany). The sonication process lasted for 40 minutes 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 minutes. The resulting supernatant, was then subjected to phytochemical analysis.

2.3.2. Extract Characterization

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

2.3.2.1. Determination of Total Anthocyanin Content

The total anthocyanin content 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 [32]. 200 µL of the plum sample was combined with 800 µL of a buffer solution with pH values of 1.0 (potassium chloride buffer) and 4.5 (sodium acetate buffer) in a spectrophotometer cuvette. After allowing the solutions to react for 15 minutes in the absence of light, the absorbance was measured at wavelengths of 520 and 700 nm. The AT content expressed in mg cyanidin 3-glucoside equivalents (C3G)/g dry weight (dw) was calculated by using the following equation:

$$\text{Total Antocyanins (mg C3G/g dw)} = (A \times \text{MW} \times \text{DF}) / (\epsilon \times l \times m) \quad (2)$$

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

2.3.2.2. Determination of Total Flavonoid Content

The measurement of the sample's total flavonoids was conducted using Kumaran and Karunakaran (2007) [33] method with slight modifications. 250 µL of plant extract were mixed with 1.25 mL of deionized water, and 0.075 mL of 5 % NaNO₂ solution. Following a 5-minute period of darkness, a volume of 0.15 mL of a solution containing 10% AlCl₃ was added. After other 6-minute rest, 0.5 mL of a 1M NaOH solution and 0.775 mL of deionized water were added into the reaction mixture. 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 R² 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).

2.3.2.3. Determination of Total Polyphenol Content

The Folin-Ciocalteu colorimetric method was employed to quantify the Total Polyphenol content [34]. In this procedure, 0.20 mL of plum extract was mixed with 15.8 mL of distilled water and 1 mL of Folin-Ciocalteu reagent. Following a duration of 10 minutes, a volume of 3 mL of a sodium carbonate solution with a concentration of 20% was added. The solution was allowed to rest for 60 minutes at ambient temperature, followed by measuring the absorbance at 765 nm. The polyphenolic compounds content was quantified in mg of gallic acid equivalents (GAE) per g of dry weight (dw) using an equation derived from the standard Gallic acid calibration curve with R² = 0.9837.

2.3.2.4. Determination of the Antioxidant Activity

The samples' antioxidant activity was assessed using the DPPH ~~technique~~ ^{method} [35]. 100 µL of diluted extract was combined with 3.9 mL of DPPH solution and agitated for 30 seconds. After incubating for 30 minutes 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 were described as µmol Trolox equivalent /g 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:

$$\text{DPPH scavenging activity (\%)} = ((A_{\text{blank}} - A_{\text{sample}}) / A_{\text{blank}}) \times 100; \quad (3)$$

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.

2.3.3. 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 CIE Lab 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 $\Delta E = (\sqrt{L^{*2} + a^{*2} + b^{*2}})$ the total color difference [36]. Browning index and yellowness index were calculated according to the equations:

$$BI = [100 (x - 0.31)] / 0.17; \quad (4)$$

where $X = (a^* + 1.75L^*) / (5.645L^* + a^* - 0.3012 b^*)$ respectively $YI = (142.86 \times b^*) / L^*$ [37].

2.3.4. Measuring Heavy Metals in Samples

~~This study used analytical grade reagents and chemicals to ensure high quality results.~~ The calibration curve's working standard solution was generated with nitric acid (HNO₃ 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 [38]. 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 soil and fruit plum sample mineralization. The laboratory materials were cleaned with a warm aqueous solution (10% HNO₃) followed by ultrapure water rinse before heavy metal analysis. Cu, Ni, Zn, and Cd concentrations in soil and fruit samples were quantified by Atomic Absorption Spectrometry (AAS ContrAA 700, Analytik Jena) with a flame atomization system (Table 1).

Table 1. Performance parameters for AAS analysis.

Parameters	Setting
Elements	Cu, Ni, Zn, 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

2.3.5. Methodology of Soil Chemical Parameters

For the determination of soil chemical parameters, standardized methods were applied according to protocols established by researchers in the field of soil science and soil chemistry. pH: measured using a pH meter according to standardized procedures [39]. Kjeldahl method was applied for total nitrogen determination [40]. Phosphoric acid extraction was used for the determination of available soil phosphorus, with subsequent measurements by spectrophotometry [41] and potassium determination by flame spectrophotometry [42]. Ca and Mg determination was performed by complexometric titration using ammonium chloride for extraction [43, 44]. Walkley-Black method was adopted for the determination of organic matter and organic carbon content in soil [45, 46].

2.4. Assessment of Health Risks in Orchard Plum

2.4.1. Factors of heavy metals transfer (MTF)

For a understanding of the intricate interactions soil - fruit and how they affect food safety, MTF is calculated by the formula [47].

$$MTF = \frac{C_f}{C_s}; \quad (5)$$

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

2.4.2. Health Risk Assessment of Heavy Metals in Plum Consumption

The potential health risk of consuming plums contaminated with heavy metals (Zn, Cu, Ni and Cd) was evaluated through the use of 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 fruit 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 [48].

$$EDI = \frac{C_m \times I_r}{B_w}; \quad (6)$$

Where, I_r is the ingestion rate of fruits (0.345 kg/adults/day, 0.243 kg/children/day), 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) [49].

The THQ associated with heavy metals is calculated by assessing the daily exposure to the reference standard oral dose (RfDo), which quantitatively measures the potential health risks posed by adults and children. For Zn, Cu, Ni, and Cd, the RfDo values are 0.3, 0.04, 0.02, and 0.0005 mg kg⁻¹ day⁻¹ [50, 47, 51].

$$THQ = \frac{EDI}{RfDo}; \quad (7)$$

Interpretation of results for THQ: THQ < 1 = low risk; 1 < THQ < 10 = moderate risk; 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.

$$HI = \sum_{n=1}^i THQ_{Zn} + THQ_{Cu} + THQ_{Ni} + THQ_{Cd}; \quad (8)$$

Where, HI < 1 is safe, whereas 1 < HI poses health risks [51].

2.5. Analyzing data305

2.5.1. Analysis of bivariate correlation306

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].

2.5.2. Analytical statistics318

The present study involved the conduction of triplicate analyses for each sample, and the results were reported as the mean $\pm$ SD. Pearson's method was utilized for correlation analysis to measure similarity. The hierarchical cluster analysis method was used for statistical toolbox in Matlab 7.9.0 (R2009b) for cluster analysis, while IBM SPSS v26 software, using the Ducan test for $p \leq 0.05$, was used for statistical data processing. Differences achieving this level of significance were considered statistically significant.

3. Results and discussions325

3.1. Soil Chemical Parameters326

Plum orchards are well adapted to the soil conditions found in our country and can thrive in the most soil types [52]. The most commonly used plum rootstock is *Prunus cerasifera*, which offers flexibility in terms of soil type [53]. Table 2 compares the chemical characteristics of conventional and ecological managed soils to determine the impact of agricultural practices on soil fertility and health. For all three varieties studied, soil chemical properties were similar, and their values were calculated as averages per system.

Table 2. Soil texture and chemical parameters.333

Texture		Loamy-clay	
Management system	Cv	Eco	
pH	7.11 $\pm$ 0.17	7.17 $\pm$ 0.11	
		ns	
Nt (%)	0.178 $\pm$ 0.00	0.206 $\pm$ 0.00	
		*	
P (mg/kg)	98.60 $\pm$ 1.88	89.70 $\pm$ 2.41	
		*	
K (mg/kg)	413.20 $\pm$ 14.68	406.87 $\pm$ 8.32	
		ns	
Ca ²⁺ sch (me/100 g sol)	13.54 $\pm$ 0.10	14.07 $\pm$ 0.25	
		ns	
Mg ²⁺ sch (me/100 g sol)	7.62 $\pm$ 0.22	7.84 $\pm$ 0.11	
		ns	
Corg (%)	2.04 $\pm$ 0.05	2.18 $\pm$ 0.06	

		ns
Humus (%)	3.47 ± 0.11	3.68 ± 0.09
		ns

Eco-ecological; Cv-conventional; ns- nesemnificative; *-semnificative.

In terms of pH, the results of the study indicate neutral values, with an average of 7.11 for the conventional system and slightly higher for the ecological system, with an average of 7.17. This difference is not statistically significant (ns) and suggests neither system exhibits extreme acid or alkaline conditions that could affect plant nutrient availability. The most favorable soils for the genus *Prunus* are those with weakly acidic or neutral pH levels (between 5.8 and 7.3) [54]. Soil pH is a fundamental attribute that influences chemical, biological, and physical processes; as such, it is considered an essential soil variable [55-57]. Soil pH is a essential factor that governs soil nutrient availability, affecting plant growth and ecosystem productivity [58].

Analysis of nutrient concentration revealed significant differences in N_t and P. In the ecological system, N_t content is higher (0.206% vs. 0.178%), and P levels are lower (89.70 mg/kg vs. 98.60 mg/kg in the conventional system). Ecological management, by encouraging biodiversity and sustainable practices, seems to contribute to better N retention, potentially reducing losses of secondary nutrients (Ca²⁺, Mg²⁺) to the environment. In contrast, conventional practices may favor the accumulation of P and K in the soil, possibly due to the intensive use of fertilizers or other specific agricultural practices [59]. These results suggest that ecological farming practices can improve the organic component.

As measured by C_{org} and humus percentage, soil organic matter is slightly higher in the ecological system (2.18% C_{org}, 3.68% humus) than in the conventional system (2.04% C_{org}, 3.47% humus). Although these differences were not statistically significant, they show a trend towards a higher accumulation of organic matter in the ecological system, which may improve soil structure in the long term and contribute to the ecological resilience of the ecosystem. Regarding cations, calcium (Ca²⁺) and magnesium (Mg²⁺) had comparable values between conventional and ecological systems, with 13.54 me/100 g soil and 7.62 me/100 g soil in the conventional system, compared to 14.07 me/100 g soil and 7.84 me/100 g soil in the ecological system, both without statistical significance (ns), indicating that both soil management systems can support adequate nutrient exchange for plum cultivation and do not have a significant effect on these essential elements.

The results obtained are in agreement with other studies on increasing organic content and micronutrients in ecological systems [60-64]. Higher P and K concentrations are also observed in the conventional system [65, 66].

3.2. Phytochemical Characterization of Plum powders

Several studies show that plums contain high levels of bioactive chemicals 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]. Table 3 summarizes the results of the phytochemical characterization of plum powders.

A class of compounds found in many fruits and vegetables is called anthocyanins. They belong to the flavonoid group. The highest level of total anthocyanins was detected in samples of "Tuleu Gras" variety, and it was found not significantly different anthocyanins values between conventional and ecological system. However, the highest contents of total polyphenols and flavonoids (7.76 ± 0.18 mg/g, 3.65 ± 0.11 mg/g dw) was identified in "Record" variety, and it was significantly different from the total polyphenols and flavonoids contents in conventional and ecological systems.

The highest antioxidant activity (25.54 ± 0.49 μM Trolox/g dw, 97.07 ± 2.75 %) was recorded in "Record" variety and was no significant differences between conventional and ecological system.

Table 3. Characterization of the phytochemicals of plum powders.

Phytochemical characteristics		Antioxidant activity		Total polyphenols	Total flavonoids	Total anthocyanins
		μM Trolox/g dw	Inhibition %	(mg GAE/g dw)	(mg CE/g dw)	(mg C ₃ G/100 g dw)
Varieties						
Tuleu Gras	Eco	22.10 ± 0.33 b	91.29 ± 0.69 ab	3.89 ± 0.12 d	1.45 ± 0.03 cd	5.17 ± 0.10 a
	Cv	21.93 ± 0.40 b	90.62 ± 1.59 ab	3.72 ± 0.09 d	1.36 ± 0.04 d	5.03 ± 0.14 a
Record	Eco	25.54 ± 0.49 a	97.07 ± 2.75 a	7.76 ± 0.18 a	3.65 ± 0.11 a	1.52 ± 0.05 b
	Cv	23.95 ± 0.64 a	96.14 ± 1.37 ab	6.67 ± 0.12 b	2.43 ± 0.06 b	1.58 ± 0.03 b
Centenar	Eco	21.70 ± 0.77 b	92.78 ± 2.28 ab	4.52 ± 0.08 c	1.63 ± 0.04 c	1.14 ± 0.01 c
	Cv	19.53 ± 0.4 c	90.34 ± 2.35 b	3.26 ± 0.02 e	1.32 ± 0.02 d	1.02 ± 0.02 c

Eco-ecological; Cv-conventional; Different letters in the same column suggest statistically significant differences ($p < 0.05$).

Our reported data are in agreement with other studies. Previous researches have shown that the contents of polyphenols in plum ranged from 186.4 mg to 391.2 mg GAE/100 g fresh weight [68]. Fresh plums had a high content of polyphenolic compounds (111 mg GAE/100 g). The characteristic polyphenolic compounds of plums (86% of total polyphenolic compounds) are neochlorogenic (3-O-caffeoylquinic) and chlorogenic (3-O-caffeoylquinic) acids [8].

In studies conducted with different plum genotypes, total phenolic content was varied between 754.0 ('Fortune') to 983.3 ('Friar') mg GAE/kg. Total flavonoid content varied from 312.3 ('Fortune') to 488.0 ('Fortune') mg CE/kg and for antioxidant activity from 72.6% ('Fortune') to 79.3% ('Friar'), respectively [69].

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

Cevallos-Casals et al. [18] 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 fresh weight. Using the DPPH technique, antioxidant activity levels were shown to be between 15 and 65% [14] 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 total phenolics and antioxidant activity throughout the commercial ripening stage [73, 74].

Although genotype is thought to be the primary cause of the differences, other factors such as 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 fruit [75, 76].

3.3. 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 powders color measurement (L^* , a^* , b^* , and parameters ΔE , C^* , h^* , BI and YI) are revealed in Table 4. L^* values, which show the lightness of the samples, ranged between 52.21 ± 0.95 (Tuleu Gras) and 56.89 ± 1.08 (Record). "Record" variety showed the highest luminosity.

According to the values of the color parameters, the fruit powder of "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 "Tuleu Gras" plum variety, which exhibited the highest value of color parameter a^* among the plum samples, can be explained [78]. The parameter a^* 's positive value indicates the tendency to display the red color. Similar findings were reported for the fruit colour on 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.

Table 4. Colorimetric parameters of plum powders.

Varieties	Management system	L^*	a^*	b^*	ΔE (total color difference)	C^* (Chroma)	h^* ($^\circ$) dual color appearance (hue angle)	BI	YI
Tuleu Gras	Eco	53.36 ± 0.80 ab	10.27 ± 0.08 a	16.47 ± 0.52 c	56.78 ± 1.08 ab	19.41 ± 0.28 b	1.01 ± 0.03 bc	50.46 ± 1.35 c	44.09 ± 1.08 b
	Cv	52.21 ± 0.95 b	9.14 ± 0.16 bc	15.33 ± 0.37 d	55.17 ± 1.48 b	17.85 ± 0.44 c	1.03 ± 0.02 b	47.06 ± 1.67 c	41.95 ± 1.09 b
Record	Eco	56.89 ± 1.08 a	8.33 ± 0.24 d	11.34 ± 0.26 e	58.94 ± 2.09 ab	14.08 ± 0.37 d	0.94 ± 0.02 d	32.54 ± 0.67 d	28.48 ± 0.89 c
	Cv	56.49 ± 1.52 ab	7.56 ± 0.11 e	10.86 ± 0.19 e	58.03 ± 1.19 ab	13.23 ± 0.42 d	0.96 ± 0.01 cd	30.75 ± 0.23 d	27.46 ± 0.67 c
Centenar	Eco	54.15 ± 1.92 ab	9.26 ± 0.23 b	26.14 ± 0.46 a	60.83 ± 0.46 a	27.73 ± 0.67 a	1.23 ± 0.03 a	76.70 ± 1.34 a	68.96 ± 1.57 a
	Cv	53.48 ± 1.09 ab	8.67 ± 0.22 cd	25.02 ± 0.13 b	59.68 ± 1.04 a	26.49 ± 0.60 a	1.24 ± 0.02 a	70.58 ± 2.00 b	66.83 ± 1.15 a

Different lower-case letters in the same column suggest statistically significant differences ($p < 0.05$).

„ b^* ” parameter represents 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 ± 1.48 and 60.83 ± 0.46 [36]. 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 "Centenar" plum variety samples and could be assigned to Maillard reactions or pigment release.

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.

3.4. Pearson Correlation Analysis of Plum Fruit Characteristics

Pearson correlation analysis was performed to determine the correlation between the phytochemical composition and colorimetric parameters in plum powders. The results are presented in Table 5. The analysis showed that there is a positive and significant correlation between L* and antioxidant activity, polyphenols, antioxidant activity and flavonoids at a 0.01 level (2-tailed). The correlation coefficients were found to be 0.992 for L* and antioxidant activity, 0.969 for L* and polyphenols, 0.989 for antioxidant activity and polyphenols, and 0.967 for polyphenols and flavonoids. The same correlation was observed when the correlations were reversed. These findings suggest that there is a positive, and a very strong relationship between these characteristics in the analyzed sample. The statistical correlation between L* and flavonoids was significant at a 2-tailed p-value of 0.05, indicating a strong positive relationship ($r = 0.897$). Similarly, a significant positive correlation was observed between flavonoids and oxidative activity ($r = 0.927$). Negative correlations are also present in the table 5 and are denoted by the symbol '-'. Overall, these findings suggest a strong correlation between these characteristics in the analyzed sample.

Table 5. Pearson correlation analyses between phytochemical composition and colorimetric parameters in plum powders

		L*	a*	b*	AA (Inhibition %)	TP	TF	TA
L*	Pearson Correlation	1						
	Sig. (2-tailed)	-						
a*	Pearson Correlation	-0.705	1					
	Sig. (2-tailed)	0.118	-					
b*	Pearson Correlation	-0.527	0.390	1				
	Sig. (2-tailed)	0.283	0.445	-				
(AA) (Inhibition %)	Pearson Correlation	0.992**	-0.809	-0.515	1			
	Sig. (2-tailed)	0.001	0.098	0.375	-			
TP	Pearson Correlation	0.969**	-0.790	-0.586	0.989**	1		
	Sig. (2-tailed)	0.007	0.112	0.299	0.001	-		
TF	Pearson Correlation	0.897*	-0.651	-0.570	0.927*	0.967**	1	
	Sig. (2-tailed)	0.039	0.234	0.316	0.023	0.007	-	
TA	Pearson Correlation	-0.781	0.669	-0.100	-0.781	-0.711	-0.615	1
	Sig. (2-tailed)	0.119	0.217	0.873	0.119	0.178	0.269	-

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).

3.5. Physical-chemical plum quality parameters

Physicochemical quality parameters of plum powders of three varieties such as Tuleu Gras, Record, and Centenar obtained by applying conventional and ecological systems were evaluated in table 6.

Table 6. Physicochemical properties of three cultivars of *Prunus domestica* L. (family Rosaceae) powders.

Characteristics	Varieties					
	Tuleu Gras		Record		Centenar	
	Cv	Eco	Cv	Eco	Cv	Eco
Weight (g)	42.78 ± 1.21	38.31 ± 0.55	83.25 ± 2.04	71.54 ± 1.86	44.31 ± 1.39	41.23 ± 1.00
	cd	d	a	b	c	cd
Stone (g)	4.46 ± 0.10	4.00 ± 0.07	3.28 ± 0.06	2.82 ± 0.01	3.17 ± 0.07	2.93 ± 0.05
	a	b	c	d	c	d

Pulp firmness (units HPE) (N/0.10 cm²)	63.15 ± 0.94 b	61.43 ± 1.11 b	68.48 ± 1.31 a	66.34 ± 1.78 ab	64.82 ± 2.30 ab	63.77 ± 1.30 ab
pH	3.61 ± 0.02 d	3.83 ± 0.02 c	4.12 ± 0.03 b	4.21 ± 0.01 a	4.08 ± 0.02 b	3.94 ± 0.04 c
Dry matter soluble (%)	20.53 ± 0.36 a	18.59 ± 0.53 bc	19.57 ± 0.28 ab	16.31 ± 0.4 d	17.83 ± 0.46 c	15.66 ± 0.49 d
Titrateable Acidity (%)	1.76 ± 0.04 a	1.19 ± 0.03 b	0.66 ± 0.01 d	0.62 ± 0.01 d	0.90 ± 0.01 c	0.83 ± 0.02 c
Total sugar (%)	10.54 ± 0.19 ab	10.72 ± 0.20 a	9.93 ± 0.27 cd	10.21 ± 0.36 ab	8.92 ± 0.18 e	9.36 ± 0.07 de
Thanoid compounds	0.07 ± 0.00 a	0.07 ± 0.00 a	0.07 ± 0.00 a	0.07 ± 0.00 a	0.07 ± 0.01 a	0.07 ± 0.00 a
C Vitamin (mg %)	8.84 ± 0.20 b	8.67 ± 0.15 b	10.03 ± 0.18 a	10.44 ± 0.05 a	8.92 ± 0.21 b	9.11 ± 0.14 b
P (mg %)	19.16 ± 0.29 b	18.85 ± 0.34 b	22.56 ± 0.43 a	22.73 ± 0.61 a	14.64 ± 0.52 c	15.94 ± 0.33 c
Ca (mg kg⁻¹ FM)	94.67 ± 1.66 a	95.64 ± 2.71 a	80.75 ± 1.15 b	83.32 ± 2.04 b	93.21 ± 2.42 a	93.74 ± 2.94 a
Mg (mg kg⁻¹ FM)	89.51 ± 2.17 c	89.73 ± 2.04 c	75.38 ± 1.30 d	92.84 ± 1.64 c	101.82 ± 0.50 b	114.54 ± 2.67 a
K (mg %)	222.97 ± 4.25 c	229.03 ± 6.15 bc	245 ± 8.69 ab	247.00 ± 5.05 a	201.00 ± 1.51 d	219.03 ± 3.83 c

Different lower-case letters in the same column suggest statistically significant differences ($p < 0.05$).

Table 6 shows that the dry matter concentration ranges between 15.66% and 20.53%, with significant variations between the two systems applied. The dry matter values, which range from 18.24 to 27.05%, are consistent with those for *Prunus domestica* L. reported in the literature [80].

The titrateable acidity ranged from $0.62 \pm 0.01\%$ in "Record" sample to $1.76 \pm 0.04\%$ in "Tuleu Gras" sample. No significant differences were noticed between the conventional and ecological system of the samples. There are significant differences in the Titrateable Acidity content, with "Tuleu Gras" variety having the greatest values of $1.76 \pm 0.04\%$ for conventional system and $1.19 \pm 0.03\%$ for ecological system, respectively and "Record", having only $0.62 \pm 0.01\%$, that with the lowest.

The acidity of domesticated cultivars, like *Prunus salicina* L., has been observed to range from 0.31 to 0.55% [81], 0.9% [82], and 0.45 to 0.67% for the fruits of "Stanley" *Prunus domestica* L. grafted on *P. cerasifera* L. rootstock [83]. The total acid content of plums (*P. cerasifera* Ehrh.) from the Mediterranean region was found to vary widely, between 0.72 and 1.81% [84]. The fruit variety, level of maturity, and growing circumstances all influence the titrateable acidity.

The preservation of the food and product depends on the Titrateable Acidity and pH values [85]. It was discovered that there was a reversed relationship between the Titrateable Acidity and pH value of all sample as indicated in Table 6. A decrease in acidity level was also indicative of an increase in pH [86].

There were statistically significant variations in the sugar content data. The plums' inherent physico-chemical traits and ripeness may be connected to the variation in sugar content. The content of total sugar was higher in $10.72 \pm 0.20\%$ in "Tuleu Gras" cultivar and lower in "Centenar" cultivar $8.92 \pm 0.18\%$. Overall, it was discovered that these results agreed with the previous findings [87, 88].

The content of C Vitamin (ascorbic acid) in the sample was measured at $8.67 \pm 0.15 - 10.44 \pm 0.05$ mg %, the highest content being in "Record" variety. There are no significant

differences in the conventional and ecological system of samples. Other results of C Vitamin are in wild plum (10.3 mg/100 g) listed in the USDA food composition database [89], and for farmed cherry plum from Turkey (43–83 mg/100 g [83].

Fruit's firmness is not solely determined by the 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 [90]. The force required to break the skin is the maximum force, and the fruit's hardness can be determined through an examination of the force/deformation curve's slope. The cultivar "Record" has the greatest firmness, with a value for maximum force of 68.48 ± 1.31 N/0.10 cm². "Tuleu Gras" has the least firmness, with values of 61.43 ± 1.11 N/0.10 cm², respectively. These cultivars' hardness 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 table 6, the mineral composition of the plum samples was dominated by Potassium (K) in "Record" variety (247.00 ± 5.05 mg %), followed by Magnesium (Mg) in "Centenar" cultivar (114.54 ± 2.67 mg kg⁻¹ FM), Calcium (Ca) in "Tuleu Gras" (94.67 ± 1.66 mg kg⁻¹ FM) and Phosphorus (P) in "Record" variety (22.73 ± 0.61 mg %). Calcium (Ca) 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 ± 2.71 mg kg⁻¹ FM, higher than the wild plums from the Northern Plains of India, which had a value of 11 mg/100 g, as reported in USDA [89]. No significant differences were recorded between the conventional and ecological systems of plum varieties regarding Ca contents.

These values are greater than the outcomes that Goosen et al. [91] had previously reported in Sourplum. While potassium concentration found in "Record" variety was in line with other studies' findings Marakoğlu et al. [92], higher potassium, magnesium, and iron levels were reported by Çalışır et al. [93].

According to earlier research on the mineral profile of carob molasses by Tounsi et al. [94], K (1900 mg/100 g) dominated the mineral composition of the samples, with Ca and Mg following in the range with values of 360 and 270 mg/100 g, respectively. The pomegranate molasses samples were shown to be rich in minerals, particularly in K (450 - 4700 mg/100g), Ca (71.88 - 1803.63 mg/100g), Mg (7.48 - 409.10 mg/100g), and Fe (1.05 - 22.99 mg/100g) [95].

According to Leterme et al. [96], several variables, including 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 diet. 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 1,000–1,200, 310–420, 4,700, 1,200–1,500, 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 [97].

3.6. Concentrations of Heavy Metals in Orchard Plum

In Table 7, a comparative analysis between conventional and ecological soil management systems has been carried out, taking into account the levels of heavy metals in soil and fruit and comparing them with the safety threshold values set in the legislation.

Table 7. Mean concentrations of heavy metals in plum orchard

	Management system	Zn (mg/kg)	Cu (mg/kg)	Ni (mg/kg)	Cd (mg/kg)
Soil	Cv	63.43 ± 1.15	91.11 ± 3.24	27.23 ± 0.21	0.41 ± 0.01
	Eco	50.07 ± 0.95	119.96 ± 2.45	13.43 ± 0.24	0.19 ± 0
	Signification	*	*	*	*

Threshold value (mg/kg)		200	100	50	1
Lower guideline value (mg/kg)		250 (e)	150 (e)	100 (e)	10 (e)
Higher guideline value (mg/kg)		400 (e)	200 (e)	150 (e)	20 (e)
Fruit	Cv	0.48 ± 0.01	0.83 ± 0.03	0.19 ± 0	0.009 ± 0.00
	Eco	0.39 ± 0.01	1.21 ± 0.03	0.12 ± 0	0.006 ± 0.00
	Signification	*	*	*	*
Safe limit**		0.60	10	10	0.02

*. $p < 0.05$, WHO/FAO, 2022. The guideline values have been defined on the basis of ecological risks (e) or health risks (t).

In the conventional soil, higher concentrations of Zn, Ni, and Cd were recorded comparing to the ecological system. However, Cu showed higher concentrations in the ecological soil, reaching 119.96 mg/kg, slightly exceeding the safe limit set at 100 mg/kg. Zn, Ni and Cd concentrations followed the trend with specific values of 63.43>27.23>0.41 (mg/kg) for conventional and 50.07>13.43>0.91 (mg/kg) for ecological. These findings indicate a potentially better efficiency of the ecological system in maintaining heavy metal concentrations within recommended limits. This observation could suggest a potential concern regarding the presence of this metal in the soil in both types of management analyzed.

Research has shown that copper concentration in ecological orchards is generally higher than in conventional grown orchards. The results of Fu [57] showed that long-term application of copper-containing fungicides resulted in a 3.5-fold increase in 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 [98]. Also, the study made Jez et al. [99] showed higher concentrations of copper in ecological grown vineyard soil than in conventional soil.

However, another study of olive production in Turkey found that reduced copper application in organic management resulted in a 50% reduction in soil copper content, highlighting the idea that organic practices can help mitigate copper accumulation in the soil [100]. 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 organic orchards compared to conventional orchards can be attributed to the widespread use of copper-based fungicides in ecological agriculture [99–101]. The annual limit of copper used in ecological agriculture is only sometimes respected, leading to higher soil concentrations [102]. In beside that, the addition of organic soil amendments, such as vermicompost tea, can increase soil copper content [103]. These factors contribute to the higher copper concentration in organic orchards comparing 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. [57] 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 organic fertilizers, which, on long term, leads to an increase in the concentration of this element in the soil.

However, it is important to note that these findings may need more consistent across studies. Other research on vineyard soils in Italy has also noticed consistent trends regarding copper behavior between conventional and ecological management [100]. Therefore, further research is needed to fully understand the relationship between copper concentration and ecological vs. conventional orchards.

Regarding metals in fruit, the trend was $Cu > Zn > Ni > Cd$, with values in the conventional system of $0.83 > 0.48 > 0.19 > 0.009$ (mg/kg) and in the ecological system of $1.21 > 0.39 > 0.12 > 0.006$ (mg/kg).

Concentrations of these metals in fruit have been the subject of numerous studies. It has been observed that the results obtained are lower comparing to other published results. Radwan and Salama [104] and Onianwa et al. [105] 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 watermelon, orange, and banana, 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, 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 [106]. In another study, the accumulation of toxic elements in various vegetables, including *Prunus armeniaca*, was analyzed, and it was found that Cu, Zn and Cd concentrations for apricot kernel peel (18.59; 1.6; 0.059 mg/kg) were higher than those in Apricot kernel (16.19 mg/kg 1.3; 0.06) with a whole fruit value of 17.94 Cu, 2 Zn and 0.058 Cd. In the case of Cd, it exceeded the maximum allowable concentration (0.2 mg/kg FAO/WHO 2021) [107]. Also, in a study conducted in Nigeria, metal concentrations in fresh fruits and vegetables ranged from 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 [108].

Finally, another study analyzed the concentration of some heavy metals in vegetable fruits (tomatoes, cucumber, watermelon) using atomic absorption spectrophotometry (AAS). Higher concentrations were found for Zn compared to our results, lower values for Cu, and exceeding the maximum allowable limit for Cd [109].

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

3.7. Pearson correlation analysis of heavy metals in plum orchard

The study of heavy metal concentrations in plum orchard soils is essential for assessing the potential impact of pollution on soil health and, thus, on horticultural production in this region. Table 8 shows the results of Pearson analysis, highlighting the correlation coefficient between the concentrations of different heavy metals in the soil.

Table 8. The correlations of metal content in the plum orchard.

		Zn (mg/kg)	Cu (mg/kg)	Ni (mg/kg)	Cd (mg/kg)
Zn (mg/kg)	Pearson Correlation	1			
	Sig. (2-tailed)	-			
Cu (mg/kg)	Pearson Correlation	0.887**	1		
	Sig. (2-tailed)	0.003	-		
Ni (mg/kg)	Pearson Correlation	0.982**	0.873**	1	
	Sig. (2-tailed)	0.000	0.005	-	
Cd (mg/kg)	Pearson Correlation	0.913**	0.786*	0.961**	1
	Sig. (2-tailed)	0.002	0.021	0.000	-

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

Based on the data provided, there seems to be a moderate positive correlation between Cu-Cd ($r=0.786$, $p=0.021$). Additionally, there are strong positive correlations between Zn-Cu ($r=0.887$, $p=0.003$) Zn-Cd ($r=0.913$, $p=0.002$) and Cu-Ni ($r=0.873$, $p=0.005$). Moreover, there are very strong positive correlations between Zn-Ni ($r=0.982$, $p=0.000$) and Ni-Cd ($r=0.961$, $p=0.000$). These correlations are considered statistically significant

since the probability associated with the Pearson correlation coefficient is 0.01, less than the assumed risk of 5%. In another literature 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 may suggest that they share the same origin or are interdependent [110]. 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 [111].

The relationship between soil heavy metal content and conventional vs. ecological fruit are presented in table 9. The data analysis reveals a statistically significant correlation between the heavy metal content of conventional managed soil and conventional fruit, with a very strong positive coefficient of $r=0.991$, $p=0.009$ significant at the 0.01 level. Similarly, a very strong positive correlation coefficient of $r=0.995$, $p=0.005$ has been noticed between soil in the ecological system and ecological fruit. These findings indicate a relationship between the heavy metal content of soil and the presence of such metals in fruit.

Table 9. The correlation between fruit- soil system

		Soil Cv	Soil Eco	Fruit Cv	Fruit Eco
Soil Cv	Pearson Correlation	1			
	Sig. (2-tailed)	-			
Soil Eco	Pearson Correlation	0.951*	1		
	Sig. (2-tailed)	0.049	-		
Fruit Cv	Pearson Correlation	0.705	0.479	1	
	Sig. (2-tailed)	0.295	0.521	-	
Fruit Eco	Pearson Correlation	0.918	0.995**	0.963*	1
	Sig. (2-tailed)	0.082	0.005	0.037	-

The significance of the correlation is established at the 0.05 (2-tailed) level for * and the 0.01 (2-tailed) level for **.

3.7.1. Metal transfer factor

Figure 3 investigates the transfer of heavy metals from soil to fruit (Zn, Cu, Ni and Cd) analyzed in conventional and ecological horticultural practices, while highlighting the importance of monitoring this phenomenon to ensure soil quality and food safety.

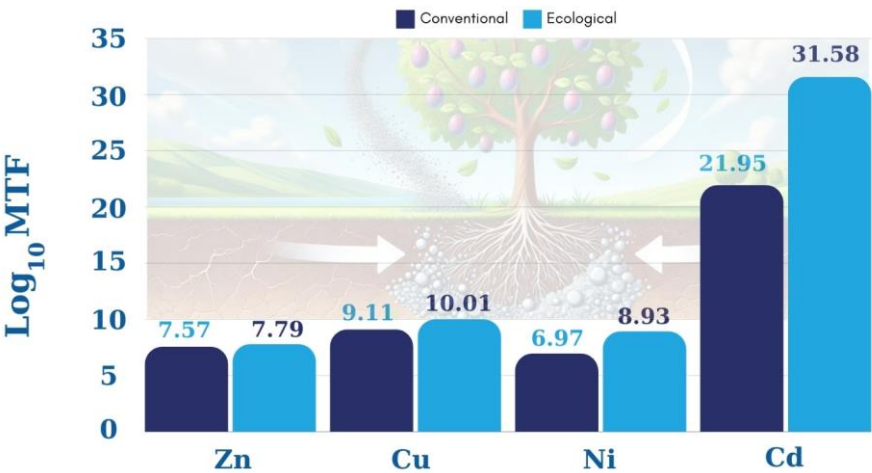


Figure 3. Metal transfer factor (Log₁₀) from soils to fruit of *Prunus domestica* L.

The translocation of metals in fruit was within permissible risk limits (≤ 1), and the order of mean values of selected metals varied between cropping systems. The sequence of mean MTF values of selected metals followed the order for the conventional system $Ni < Zn < Cu < Cd$, and for the organic system, the order was $Zn < Ni < Cu < Cd$. Thus, from figure 3, it is clear that horticultural practices, whether conventional or organic, can influence the transfer of heavy metals into fruit. MTF from soil to fruit has been investigated in several studies. Nitu et al. [112] studied the accumulation and transfer coefficient of heavy metals in blueberry and raspberry fruit. The authors concluded that all concentrations of Cu and Zn presented a low risk for human consumption. Pruteanu et al. [113] examined Cu accumulation and transferal from soil to vegetables and fruits. The authors showed the presence of copper in soils and its accumulation in the vegetative parts of vegetables and fruit consumed by humans. Waida et al. [114] investigated different edible plants and the transfer factor for different metals. Thus he 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. [115] assessed Cd and Zn contamination in soil and found that Zn translocation in *Solanum lycopersicum* was associated with organic fertilizer use.

3.8. Assessment of Health Risks of Metals in Plum Fruit

The daily uptake of trace metals for children and adults in our sample is presented in Table 10.

Table 10. 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}	

The study found that EDI values for accumulated elements in plums followed the same trend for both children and adults, with $Cu > Zn > Ni > Cd$. Comparative analysis showed that the highest EDI value was recorded for Cu (8.99×10^{-3}) in the ecological system for both children and adults, followed by the value in the conventional system (6.17×10^{-3}). Among all the elements, Cd had the lowest EDI values through plum consumption in adults and children: Cd (2.84×10^{-5}) had lower values in the ecological system than in the conventional system.

In a study of mango fruit, 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} ; 1.56×10^{-5} to 1.75×10^{-4} and ND-

1.7×10^{-4} mg/kg/day, respectively. In various samples studied (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 [116]. The values for Cu and Zn were 0.0015–0.012 and 0.026–0.421 mg/kg/day, respectively, which were higher than those in the present study [117].

The Target Hazard Quotient (THQ) through fruit consumption is a real indicator of chemical pollutants presence. Although it can't provide an accurate risk assessment, THQ specifies an alert level [118]. In this research, the THQ for all metals was <1 , indicating that metal intake through plum fruit consumption doesn't pose a health risk upon the population from the study area.

The maximum 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 minimum THQ value calculated was for Zn, ranging from 9.63×10^{-3} to 1.19×10^{-2} .

According to the results in Table 10, the THQ values for Cd were lower than those reported in the literature for the South Ethiopian region [51], where Cd values of 3.16×10^{-1} and 3.4×10^{-1} are reported for adults. Lower Cd values have also been reported in Egypt, which estimates values for Cd between 0.672432 and 1.267432 [116].

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 [116], where HI ranged from 0.912073 to 1.644178. In another study focusing on mango fruit, 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.

However, the concentration of heavy metals in avocado and lemon fruits grown near mining activities in Zambia did not pose any health risks to consumers [119].

4. Conclusions

This study looked at three different plum cultivars (Tuleu Gras, Record, and Centenar) that were grown in an orchard in the northwestern of Romania using different management systems. It also looked at phytochemical characteristics, heavy metal concentrations, and antioxidant activity. Despite the fact that certain heavy metals were found in the fruit, the study concluded that all three plum cultivars examined were safe for ingestion by humans.

Specifically, "Record" variety had a higher content of total phenols and flavonoids and a superior antioxidant capacity than the other two cultivars. The study highlighted the significance of the relationship between heavy metals and the antioxidant activity of plum fruits in promoting human health, especially in the presence of environmental challenges. The variations in the elemental chemical composition and antioxidant capacity of plum selections were attributed to genetic variability, growing seasons, geographic origin, cultivars and other horticultural techniques. The study emphasized the importance of regulatory monitoring of heavy metal levels in the production area to ensure the supply of healthy and safe food. These findings underscore the necessity of adopting sustainable crop management and horticultural practices to protect the environment and consumer health.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, M.R.; methodology, I.G.C., F.S., D.T.; software, D.T.; validation, G.J.; formal analysis, M.R., I.G.C., F.S.; investigation, M.R., I.G.C., F.S., D.T.; data curation, M.R., D.T.; writing—original draft preparation, M.R.; writing—review and editing, F.S., I.G.C., D.T., G.J.; visualization, G.J.; supervision, G.J. All authors have read and agreed to the published version of the manuscript.

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