applied sciences

MDPI

Article

Applications of Spectroscopy in the Study of Bioactive Compounds from *Cornus mas* L.

Carmen Mihaela Topală [1], Loredana Elena Vijan [1,*], Oana Hera [2,*] and Monica Sturzeanu [2]

[1] Faculty of Sciences, Physical Education and Computer Science, Pitesti University Centre, The National University of Science and Technology Politehnica Bucharest, 1 Targu din Vale Street, 110040 Pitesti, Romania; carmen.topala@upb.ro

[2] Research Institute for Fruit Growing (RIFG) Pitesti, 402 Marului Street, 117450 Pitesti, Romania; sturzeanu1980monica@yahoo.it

* Correspondence: loredana.vijan@upit.ro (L.E.V.); oana.hera@yahoo.com (O.H.)

Abstract

Five *Cornus mas* L. genotypes were analysed based on their attractive colour and high productivity. The 'Bordo' cultivar stood out, demonstrating the highest berry weight (3.07 g) and yield per plant (8.24 kg). Close behind was the MH-7-17 selection, with an average yield of 7.37 kg per plant. Both the 'Bordo' cultivar and the MH-7-17 selection exhibited excellent agronomic potential, making them ideal candidates for large-scale cultivation. UV-Vis absorption spectroscopy was used to quantify the fruits' levels of sugars, polyphenols, flavonoids, tannins, anthocyanins and carotenoids (lycopene and β-carotene) and to evaluate their antioxidant capacity. The 'Bordo' cultivar had the highest carotenoid content (0.88 mg lycopene and 2.47 mg β-carotene per 100 g), while the TG-J-9-17 and TG-J-20-17 selections had the highest total content of sugars, polyphenols, flavonoids, tannins and anthocyanins and the highest antioxidant capacity. According to the correlations analysis, bigger fruit (which correlated to higher yield) had higher carotenoid content, although lower-level tannin (TTC), flavonoid (TFC), anthocyanin (TAC), and sugar (TSC). Also, total phenolic content (TPC) was positively correlated to TTC, TFC, and radical scavenging activity (RSA), while TFC was positively correlated to TTC, TAC, RSA, but also to TSC. Other positive correlations were those found between TTC and RSA and between lycopene and β-carotene. FTIR spectroscopy was used to identify the characteristic vibrations of the biochemical constituents. Processing the FTIR data using chemometric techniques (principal component analysis and hierarchical clustering analysis) revealed consistent clustering patterns between samples with similar characteristics.

Keywords: *Cornus mas* L.; polyphenols; flavonoids; anthocyanins; lycopene; β-carotene; FTIR spectroscopy; principal component analysis; hierarchical clustering analysis

Check for updates

Academic Editors: Antonios E. Koutelidakis, Ioannis Kourkoutas, Andreas Tzakos, Aikaterini Papadaki, Nikolaos Kopsahelis and Monica Gallo

Received: 29 November 2025
Revised: 14 January 2026
Accepted: 16 January 2026
Published: 19 January 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

1. Introduction

The genus *Cornus* comprises around 70 species of woody plants belonging to the *Cornaceae* family [1]. Often referred to as dogwoods, many of these species are cultivated as ornamental plants and are distinguished by their flowers, fruits and distinctive bark [2,3]. One notable species is *Cornus mas* L., which is native to southwestern Asia and southern Europe [4]. It is cultivated for the organoleptic properties of its fruit and its medicinal uses. The fruits are typically olive-shaped, ranging in colour from shiny red to yellow [1], and contain a single seed. The cornelian cherry tree is a familiar sight in Romanian forests and scrublands [5]. It is also cultivated on a small scale for ornamental purposes in private

spaces, such as gardens, parks and nurseries. The genus includes species such as *Cornus mas* and *C. sanguinea*, which thrive in sunny or partially shaded areas [6,7]. These species can withstand low temperatures and various soil types, including wet and dry soils, even on less fertile land [8]. Despite its potential for large-scale cultivation [9], however, the cornelian cherry remains a niche crop in Romania. A variety of products are made using the ripe fruit, including juices, sweets, jams and brandy, as well as cosmetics containing fruit extracts [10].

Cornus mas L. contains a variety of bioactive compounds, including polyphenols, anthocyanins, flavonoids, ascorbic acid and iridoids [11]. These natural compounds give the plant its strong antioxidant properties and therapeutic potential, making it an important addition to the human diet. Flavonoids, and specifically the subclass known as anthocyanins, contribute colour to fruits and could be used to replace synthetic pigments with natural ones [12]. The cornelian cherry contains a wide variety of phenolic compounds, including the following acids: gallic, chlorogenic, ellagic, ferulic, coumaric, salicylic and caffeic, as well as the following flavonoids: catechin, epicatechin, quercetin, myricetin and kaempferol [13–15]. Apart from these, the cornelian cherry also contains anthocyanins. In fact, it has been reported that *Cornus mas* L. has a higher overall anthocyanin content than other berries [16]. High concentrations of the following anthocyanins have been found in cornelian cherries: cyanidin 3-O-glucoside, cyanidin 3-O-galactoside, cyanidin 3-O-rutinoside, delphinidin 3-O-galactoside, pelargonidin 3-O-galactoside and pelargonidin 3-O-glucoside [10,13,17,18]. It is well known that anthocyanins have antioxidant and anti-inflammatory properties. Four iridoids (loganic acid, cornuside, loganin and sweroside) have been identified in the fruit of *Cornus mas* L., whereas secologanin has only been found in the leaves [18]. These compounds play a crucial role in defence mechanisms against environmental threats such as insects and diseases [19].

UV-Vis absorption spectroscopy is a useful technique for identifying and quantifying bioactive compounds in plants. By measuring the absorption of light at specific wavelengths, it is possible to determine the concentrations of these compounds and gain insight into their electronic structure. UV-Vis spectroscopy can be used to quantify nitrates and nitrites in vegetable solutions [20,21], vitamins (e.g., A, C and E) [22–24] and other soluble compounds resulting from enzymatic reactions [25,26]. In these reactions, selective coloured complexes are formed, and absorption is measured at a specific wavelength. The concentration of these compounds can therefore be determined by comparing the absorption of samples with calibration curves created using known standards. This technique can also be used to study photosynthetic efficiency and plant health, or to monitor abiotic stress (e.g., drought or excessive light exposure) by quantifying pigments such as chlorophylls, carotenoids, and xanthophylls [27–29]. After extraction with organic solvents, quantifying phenolic compounds and flavonoids enables the evaluation of antioxidant activity and comparison of different genotypes or treatments applied to the plant [30–33]. UV-Vis spectroscopy is a rapid method of monitoring the progress of a reaction [34–36]. This method can be used alongside other analytical techniques, such as high-performance liquid chromatography (HPLC) and Fourier transform infrared absorption spectroscopy (FTIR), to provide a comprehensive characterisation of the phytochemical composition. As it is fast, simple, non-destructive, relatively inexpensive, and accessible, UV-Vis absorption spectroscopy is ideal for routine analysis and rapid screening, enabling the precise determination of a wide range of compounds. However, UV-Vis spectroscopy has limitations: it cannot provide detailed structural information without other techniques (such as mass spectrometry or nuclear magnetic resonance spectroscopy), and it does not detect non-absorbing compounds in the UV-Vis range (e.g., many transparent molecules).

FTIR spectroscopy is a rapid, non-destructive technique that is widely used in plant and food science to characterise biochemical constituents, including phenolic compounds, sugars, organic acids, pigments and structural polysaccharides. Previous studies have demonstrated the suitability of FTIR spectroscopy for evaluating the influence of genotype, environmental factors, and phytosanitary status on the biochemical profile of plant materials, such as leaves and fruits, highlighting its potential for compositional fingerprinting of bioactive compounds [30,37]. ATR-FTIR has also been successfully employed to characterize plant-derived matrices and agricultural products, providing complementary information to conventional chemical analyses by identifying characteristic vibrational bands associated with functional groups of phenolics, flavonoids, and carbohydrates [38,39]. Moreover, FTIR spectroscopy has been effectively used in combination with classical analytical methods to evaluate antioxidant-related compounds and to support the interpretation of nutraceutical properties in fruits, leaves, and processed food products [40,41]. ATR-FTIR has also been successfully used to characterise plant-derived matrices and agricultural products. It provides complementary information to that obtained through conventional chemical analyses by identifying characteristic vibrational bands associated with the functional groups such as those found in phenolic compounds, flavonoids and carbohydrates [29,30]. Moreover, FTIR spectroscopy has been effectively used in combination with classical analytical methods to evaluate antioxidant-related compounds and to support the interpretation of nutraceutical properties in fruits, leaves, and processed food products [40,41]. However, FTIR spectroscopy provides general information about the compounds present and does not detail each individual component.

In this study, UV-Vis absorption spectroscopy was employed to quantify the levels of sugars, polyphenols, flavonoids, tannins, anthocyanins and carotenoids (lycopene and β-carotene) in the fruit, as well as to evaluate the antioxidant capacity of the ethanolic extracts. The dosage of these compounds using UV-Vis spectroscopy has been carried out over time in different countries for the *Cornus mas* L. species harvested from spontaneous flora. This research is notable because it was conducted on a real scale in the Research Institute for Fruit Growing (RIFG) Pitesti, Romania. The aim was to identify the most productive and highest quality variety of *Cornus mas* L. The UV-Vis results were validated using the characteristic vibrations of the biochemical constituents, as determined by FTIR spectroscopy, in fruit powders produced through slow drying at temperatures ranging from 60 to 80 °C. The FTIR data were then processed using chemometric techniques, such as principal component analysis (PCA) and hierarchical clustering analysis (HCA), to identify groups of samples with similar characteristics. While FTIR is a well-established method, its novelty in this study lies in its targeted application to the 1380–1000 cm^{-1} region, combined with exploratory chemometric analysis to assess compositional similarities among fruit samples subjected to identical drying conditions. In future, we will analyse slowly dried or freeze-dried fruit powders using a combination of UV-Vis and FTIR spectroscopy alongside HPLC chromatography. This will enable us to compare the effect of different drying methods on the quality of the final product, helping us to determine the most effective method.

2. Materials and Methods

2.1. Chemicals and Reagents

All chemicals and reagents were purchased from Merck-Sigma-Aldrich, Darmstadt, Germany.

2.2. Plant Material

In the present study, five *Cornus mas* L. genotypes were evaluated, including the registered cultivar 'Bordo' and four advanced selections: TG-J-20-17, TG-J-9-17, MS-40-17, and MH-7-17. These materials originate from selection programs conducted at the Research Institute for Fruit Growing (RIFG) Pitesti, Romania, and represent distinct accessions obtained from spontaneous or semi-wild populations.

The 'Bordo' cultivar, developed by P. Mladin, Gh. Mladin, M. Coman, I. Ancu and S. Nicolae [42], was obtained through selection from spontaneous flora and officially registered in 2013. Its fruits are large and range in colour from dark red to burgundy. On average, they measure 2.32 cm in length and 1.52 cm in width and weigh 2.70 g. The average weights of the kernel and pulp are 0.45 g and 2.15 g, respectively, resulting in a pulp yield of 75%. 'Bordo' is an early and productive cultivar, with yields ranging from 15 to 20 kg per plant. Ripening occurs during the first half of August.

The TG-J-20-17 selection originates from individual plants identified within local spontaneous populations in Targu Jiu, Romania. The fruits are large and elliptical, exhibiting dark red pigmentation at full maturity. The genotype is characterised by above-average fruit size, a firm mesocarp, and a high pulp-to-kernel ratio. Spectroscopic analyses indicate elevated levels of polyphenols and flavonoids. TG-J-20-17 exhibits stable productivity and uniform fruit development. Ripening occurs in early September.

The TG-J-9-17 selection, which is also derived from the natural flora of Targu Jiu in Romania, produces medium to large, ovoid fruits that are intensely red at maturity. The mesocarp displays good firmness and a balanced sweet–acid taste profile. Biochemical characterisation reveals a high anthocyanin concentration. This selection is considered suitable for experimental cultivation and further breeding due to its good productivity. The ripening period is mid-August.

The MS-40-17 selection originates from natural germplasm in Mures County, Romania. It produces medium-sized fruits with uniform ruby-red pigmentation. Spectroscopic evaluation has confirmed the genotype's high pulp yield and elevated phenolic content. MS-40-17 demonstrates consistent annual productivity and adaptability to various soil conditions. Fruit maturation occurs in mid-August.

The MH-7-17 genotype is derived from individual selection within spontaneous populations in Mehedinti County, Romania. The fruits are visually appealing, with a dark red, glossy skin and medium size, as well as aromatic, dense pulp. This selection is notably rich in bioactive compounds, particularly flavonoids and anthocyanins. MH-7-17 shows stable productivity across years. Ripening takes place at the end of August.

The research was conducted in an open-field experimental setting at the Fruit Growing Research Institute (RIFG) in Pitesti, Romania (44°54′12″ N, 24°52′18″ E, at an altitude of 284 m) during the 2023–2024 period.

2.3. Biochemical Parameters Determined from Ethanolic Extracts

One gram of each sample was treated with 10 mL of an 8:2 ethanol/water mixture (*v*/*v*) in a VX-200 Vortex Mixer (Corning-Labnet, Corning Life Sciences, Tewksbury, MA, USA) at 3000 rpm for two minutes. The samples were then placed in a 40 kHz ultrasonic bath (ULTR-2L0-001, Labbox Labware, Premià de Dalt, Barcelona, Spain) for 30 min. The temperature of the ultrasonic bath was carefully monitored to ensure that it did not exceed 40 °C. They were then centrifuged at 6000 rpm for a further 30 min using a Spectrafuge 6c centrifuge (Labnet International Inc., Edison, NJ, USA). This process was repeated, involving an additional round of vortexing, ultrasonication and centrifugation.

The total polyphenol (TPC), flavonoid (TFC) and anthocyanin (TAC) content, as well as DPPH radical scavenging activity (RSA%), were determined in the resulting extracts

according to the methodology proposed by Stamin et al. (2024) [30]. The results were reported as mg of gallic acid equivalents (GAE), mg catechin equivalents (CE), and mg cyanidin-3-glucoside equivalents (C3GE) per 100 g of fresh weight (FW), respectively, using the calibration curves presented in Table 1.

Table 1. Calibration curves for the total content of sugars (TSC), phenolic compounds (TPC), flavonoids (TFC), and anthocyanins (TAC).

Parameters	Calibration Curve	R^2	y	x
TSC	y = 0.0281 + 0.1593x	0.9989	the absorbance of the samples at 490 nm	the concentrations of glucose, which ranged from 0.54 to 10.8 mg/L
TPC	y = 0.0358 + 0.2649x	0.9992	the absorbance of the samples at 765 nm	the concentrations of gallic acid, which ranged from 0.1 to 1 mg/L
TFC	y = −0.0473 + 2.9818x	0.9993	the absorbance of the samples at 510 nm	the concentrations of catechin, which ranged from 0.1 to 0.6 mg/mL
TAC	y = 0.0029 + 0.1699x	0.9987	the absorbance of the samples at 520 nm	the concentrations of cyanidin 3-glucoside, which ranged from 0.1 to 0.7 mg/L

To determine the RSA%, 2.97 mL of a 10^{-4} mol/L DPPH solution in methanol was mixed with 0.03 mL of each ethanolic extract. The mixtures were shaken thoroughly and left to stand in the dark at room temperature for 30 min. Absorption spectra were then recorded, and the absorbance values at 517 nm were noted.

2.4. Biochemical Parameters Determined from Aqueous Extracts

One gram of each sample was treated with 10 mL of distilled water. The samples were then vortexed at 3000 rpm for 2 min using a VX-200 Vortex Mixer. They were then placed in an ultrasonic bath at 80 °C for 30 min. Finally, the supernatant from each sample was separated by filtering it through Whatman No. 1 filter paper.

Total tannin content (TTC) was determined using the methodology proposed by Giura et al. (2019) [31], and total sugar content (TSC) using the methodology proposed by Stamin et al. (2024) [30]. The results were reported as mg of gallic acid equivalents (GAE) and g of glucose equivalents (GluE) per 100 g of fresh weight (FW), respectively.

2.5. Determination of Lycopene and β-Carotene Content

The lycopene and β-carotene content were spectrophotometrically determined in the resulting supernatant from the extraction of 4 g of each sample in a 2:1:1 volumetric mixture of hexane, ethanol, and acetone according to the methodology proposed by Tudor-Radu et al. (2016) [32]. Results were reported as mg of lycopene or β-carotene per 100 g of fresh weight (FW).

2.6. UV-Vis and FTIR Analysis

UV-Vis spectra were recorded using a PerkinElmer Lambda 25 spectrometer (Shelton, CT, USA), and the resulting data were analysed using OriginPro 7.0 software.

Attenuated total reflection (ATR) FTIR spectra were obtained using a JASCO 6700 FTIR spectrometer (Madison, WI, USA), which was equipped with a Pike Technologies ATR diamond crystal accessory and accompanied by Spectra Manager II software (JASCO, Hachiōji, Tokyo, Japan). Three scans were accumulated and recorded for each spectrum at a resolution of 4 cm^{-1}, with 32 scans per sample, covering a range from 4000 to 400 cm^{-1}. Infrared spectra were exported from Spectra Manager in ASCII (dx) format and analysed using chemometric techniques in Edition X 10.4 of the Unnascrambler software (Camo, Oslo, Norway). The FTIR spectra were pre-processed using a second-derivative Savitzky–Golay transformation with a 15-point smoothing window and a second-order polynomial, to enhance spectral resolution and minimize baseline effects. The use of

spectral derivatives with the Savitzky–Golay algorithm as a chemometric pre-processing technique has been widely reported in FTIR spectroscopy-based classifications [38–40]. The FTIR spectra were analysed within the 1380–1000 cm^{-1} spectral window, a region rich in vibrational bands associated with phenolic functional groups (C–O stretching, aromatic C–C and ring vibrations). Principal component analysis (PCA) was applied to the pre-processed dataset to reduce dimensionality and visualize major sources of spectral variance. Cross-validation was performed using the Singular Value Decomposition (SDV) algorithm.

FTIR spectra were recorded in triplicate for each sample, and the averaged spectra were used for chemometric analysis, thereby minimising instrumental variability. Principal component analysis (PCA) was employed as an exploratory chemometric approach to investigate variability and similarity in the FTIR spectra. Due to the limited number of samples, PCA was not used for statistical discrimination, but rather to highlight qualitative trends and relationships within the dataset. Consequently, the PCA results are intended solely to support the qualitative interpretation of spectral variability and complement conventional FTIR band assignments. Additionally, hierarchical cluster analysis (HCA) was performed using Ward's linkage method and Euclidean distance to assess sample grouping based on overall spectral similarity, thereby supporting the PCA interpretation.

2.7. Statistical Analysis

Three extracts of each type were prepared from every sample, and all analyses were consequently performed in triplicate.

The results were analysed using Microsoft Excel 2010 and IBM SPSS Statistics 26.0. One-way ANOVA and Duncan's multiple range tests were performed at $p < 0.05$. All data are reported as the mean (X) ± standard deviation (SD).

3. Results and Discussion

To identify the most productive and highest-quality variety of *Cornus mas* L. cultivated at the Research Institute for Fruit Growing in Pitesti, Romania, several key parameters were assessed. These included fruit production, berry weight, total polyphenol content (TPC), total flavonoid content (TFC), total anthocyanin content (TAC), total tannin content (TTC), total sugar content (TSC), lycopene content, β-carotene content and DPPH radical scavenging activity (RSA%).

A significant breeding goal for the cornelian cherry is to produce more attractive fruit, for example, by increasing fruit size or improving its taste. In terms of berry weight, the 'Bordo' cultivar performed best, with an average berry weight of 3.07 g—significantly higher than the other genotypes (Table 2). This larger fruit size could be advantageous for sales in the fresh produce market, where consumers often prefer larger fruits. In contrast, the TG-J-20-17 selection produced the smallest fruit, with an average weight of 1.35 g, which may limit its appeal for fresh consumption but could still be valuable for processing into products such as jams or juices. Consistent with our values, Hassanpour et al. (2012) [43] reported that the average weight of berries ranged from 1.499 to 3.29 g for 20 *Cornus mas* L. accessions from the Horand and Kalibar regions in East Azerbaijan. Other studies indicate that cornelian cherry berry weight ranges from 2.7 to 5 g [44] or 3.6 to 4.8 g [45]. In terms of yield per plant, the 'Bordo' cultivar was the clear leader, achieving an average yield of 8.24 kg per plant. The MH-7-17 selection followed closely behind with an average yield of 7.37 kg per plant. These two genotypes demonstrated the greatest agronomic potential, making them ideal candidates for large-scale cultivation. At the other end of the spectrum, the TG-J-20-17 selection produced the lowest yield at 3.93 kg per plant. Between 2007 and 2011, Dokoupil and Řezníček (2013) [46] analysed seven varieties of *Cornus mas* L., finding that the 'Jaltský' cultivar had the lowest yield (5.07 kg per plant), while the 'Fruchtal'

cultivar was one of the most productive (6.99 kg per plant). Klimenko (2004) [47] stated that a wild cornelian cherry bush could yield 2.8–10 kg of fruit, whereas cultivated trees in an orchard could produce up to 80 kg per bush, depending on growing conditions, age and orchard technology.

Table 2. Variations in the berry weight, fruit production, content of sugars (TSC), phenolic compounds (TPC), tannins (TTC), flavonoids (TFC), anthocyanins (TAC), lycopene, β-carotene and the DPPH radical scavenging activity (RSA%) of *Cornus mas* L. fruits depending on genotype.

Parameters	TG-J-20-17	TG-J-9-17	MS-40-17	MH-7-17	Bordo
Berry weight, g/fruit	1.35 ± 0.29 ^{d}	1.97 ± 0.40 ^{b}	1.72 ± 0.28 ^{c}	1.74 ± 0.11 ^{c}	3.07 ± 0.15 ^{a}
Fruit production, kg/plant	3.93 ± 0.35 ^{c}	4.60 ± 0.66 ^{c}	6.37 ± 0.61 ^{b}	7.37 ± 0.55 ^{a}	8.24 ± 0.31 ^{a}
TSC, g GluE/100 g FW	9.56 ± 0.05 ^{a}	9.29 ± 0.07 ^{b}	8.86 ± 0.10 ^{c}	8.70 ± 0.06 ^{d}	7.33 ± 0.04 ^{e}
TPC, mg GAE/100 g FW	724.87 ± 32.37 ^{b}	893.29 ± 60.18 ^{a}	659.99 ± 32.60 ^{b}	727.98 ± 35.56 ^{b}	684.95 ± 58.97 ^{b}
TTC, mg GAE/100 g FW	438.02 ± 16.71 ^{b}	577.60 ± 31.40 ^{a}	359.24 ± 43.10 ^{c}	435.19 ± 19.22 ^{b}	403.71 ± 15.39 ^{bc}
TFC, mg CE/100 g FW	101.31 ± 3.26 ^{a}	102.25 ± 3.52 ^{a}	86.89 ± 2.87 ^{b}	91.27 ± 3.28 ^{b}	80.64 ± 2.56 ^{c}
TAC, mg C3GE/100 g FW	13.97 ± 0.32 ^{a}	10.58 ± 0.53 ^{b}	10.23 ± 0.47 ^{bc}	9.98 ± 0.57 ^{bc}	9.43 ± 0.33 ^{c}
mg lycopene/100 g FW	0.70 ± 0.01 ^{e}	0.84 ± 0.01 ^{b}	0.76 ± 0.01 ^{d}	0.80 ± 0.01 ^{c}	0.88 ± 0.01 ^{a}
mg β-carotene/100 g FW	2.27 ± 0.01 ^{c}	2.32 ± 0.01 ^{b}	2.06 ± 0.02 ^{e}	2.15 ± 0.01 ^{d}	2.47 ± 0.01 ^{a}
RSA, %	58.11 ± 0.06 ^{b}	59.31 ± 0.07 ^{a}	53.04 ± 0.06 ^{e}	56.44 ± 0.04 ^{c}	55.95 ± 0.06 ^{d}

Means with the same letter are not significantly different at 5% level.

As shown in Table 2, the total sugar content (TSC) of *Cornus mas* L. fruits ranged from 7 to 10 g glucose equivalent (GluE)/100 g. TG-J-20-17 had the highest TSC (9.56 g/100 g), followed by TG-J-9-17 (9.29 g/100 g), MS-40-17 (8.86 g/100 g) and MH-7-17 (8.70 g/100 g). These results suggest that these genotypes may be more suitable for fresh consumption or for producing sweeter processed foods. With a total sugar content of 7.33 g/100 g, the 'Bordo' cv. was the least sweet of the genotypes. This could affect its marketability in regions where sweetness is highly valued. The TSC values found in this study are within the range of variation in this indicator in Turkish *Cornus mas* L. varieties (7.7–15.4%) [48,49], but are lower than those observed in Ukrainian (9.14–16.41%) [45], Polish (10.1–16.4%) [50] and Serbian (13.49–25.23%) [51] varieties.

The TPC, TTC, TFC, TAC and RSA% values of the five *Cornus mas* L. varieties were found to range from 659.99 to 893.29 mg GAE/100 g, 359.24 to 577.60 mg GAE/100 g, 80.64 to 102.25 mg CE/100 g, 9.43 to 13.97 mg C3GE/100 g and 53.04 to 59.31%, respectively. These values are higher than those reported by other researchers. For example, the TPC values of ten *Cornus mas* L. varieties were found to range from 217 to 614 mg GAE/100 g [44]. The TPC and TAC values of wild-growing cornelian cherry samples harvested in 2018 from twelve different locations in Turkey's Çorum province were found to range from 230.36 to 559.82 mg GAE/100 g and 69.2 to 200.5 mg C3GE/100 g, respectively [49]. Cosmulescu et al. (2019) reported TPC values ranging from 163.69 to 359.28 mg GAE/100 g for six cornelian cherry genotypes selected from spontaneous Romanian flora [15]. Hassampour et al. (2011) [52] reported higher TPC values than those reported in our study, with values ranging from 1097.19 to 2695.75 mg GAE/100 g. They also reported higher TFC and TAC values, with values ranging from 321.71 to 669 mg CE/100 g and from 106.89 to 442.11 mg C3GE/100 g, respectively, for six cornelian cherry genotypes from a fruit garden collection in East Azerbaijan Province (Arasbaran). These differences can be explained by the fact that variety, location, and environmental conditions are known to influence the biochemical parameters of fruits.

With a total polyphenol content (TPC) of 893.29 mg GAE/100 g, the TG-J-9-17 genotype is well-suited to functional food production and industrial applications. TG-J-9-17 also recorded the highest levels of flavonoids (102.25 mg CE/100 g) and radical scavenging activity (RSA) at 59.31%, further reinforcing its position as the genotype with the strongest overall antioxidant potential. The TG-J-20-17 selection had the highest total anthocyanin

content (13.97 mg C3-GE/100 g), which is linked to benefits for cardiovascular health. Despite its lower yield, the higher anthocyanin levels of TG-J-20-17 make it a valuable genotype for nutraceutical and culinary applications, where anthocyanins are prized for their colour and health benefits. In terms of total tannin content, which contributes to astringency and antioxidant properties, the TG-J-9-17 selection led with 577.6 mg GAE/100 g, followed by MH-7-17 and 'Bordo', which had comparatively lower levels. Tannins are known for their role in antioxidant defence and potential health benefits, and they significantly contribute to the quality of the fruit in terms of its health-promoting and sensory characteristics. Carotenoids such as lycopene and β-carotene are essential for eye health and for protecting against free radicals. Lycopene is renowned for its potent antioxidant properties and its ability to help prevent chronic diseases, such as cancer and heart disease. The 'Bordo' cultivar had the highest carotenoid content, with 0.88 mg/100 g of lycopene and 2.47 mg/100 g of β-carotene. Aurori et al. (2023) [11] found that the fruits of *Cornus mas* L., harvested from shrubs growing on steep hillsides in Cluj County, Romania, in 2020, contained low levels of carotenoid pigments (0.38 mg/100 g). Antoniewska-Krzeska et al. (2022) [53] demonstrated that the leaves of the plant are its richest source of carotenoids, particularly β-carotene (8845 mg/100 g). These levels are much higher than those found in *Cornus mas* L. fruit (0.487 mg/100 g), which was collected from trees in the M. M. Gryshko National Botanical Garden of the National Academy of Sciences of Ukraine in Kyiv in 2020.

Studying the correlations between morpho-productive parameters and the bioactive compounds found in *Cornus mas* L. fruits provide insight into how genetic variation influences their quality and nutritional value. Table 3 shows the strength of the Pearson correlations between fruit production and fruit weight, as well as a range of significant biochemical compounds such as sugars, polyphenols, flavonoids, anthocyanins, lycopene and β-carotene, and the antioxidant capacity as determined by the DPPH method (RSA%). Analysing these data provides an in-depth understanding of the interdependencies between the chemical profile and the morphological characteristics of the fruits. The first notable finding is the strong correlation between fruit weight and production (Table S1). However, both fruit production and weight are negatively correlated with the content of bioactive compounds, such as TPC, TFC and TAC. For instance, fruit production exhibits a substantial negative correlation with TFC ($r = -0.919$ **) and TAC ($r = -0.815$ **), indicating that highly productive genotypes tend to exhibit lower antioxidant levels. This phenomenon is common in many fruit species, where a physiological trade-off between fruit production and secondary metabolite concentration is observed. According to the growth—defence trade-off theory [54], plants have limited resources that must be allocated to either growth and production (primary metabolism) or defence mechanisms (secondary metabolism). By analysing eight species of fleshy fruit, including three herbaceous species (eggplant, pepper and cucumber), three tree species (apple, peach and clementine) and two vine species (kiwi fruit and grape), Roch et al. (2020) [55] revealed a strong connection between internal composition and growth dynamics. Using metabolic modelling, the authors demonstrated that fruits with a high growth rate prioritise cell wall and protein synthesis to support rapid biomass expansion. Conversely, fruits with slower growth rates divert metabolic fluxes towards the accumulation of total polyphenols (secondary metabolites), exhibiting a higher rate of cellular respiration by mobilising the citric acid cycle (TCA) in addition to glycolysis. The authors emphasise that nitrogen metabolism is the key factor dictating the growth–defence trade-off, controlling the balance between biomass production and the fruit's chemical defences. Similar findings were reported by Park et al. (2022) [56], who analysed the primary and secondary metabolites present in *Cornus officinalis* fruits at four developmental stages: green, light red, red, and fully ripe. The study revealed that the content of total sugars, total anthocyanins and carotenoids increased with advancing

maturity stages, while the content of triterpenes and phenolic compounds decreased during fruit development. Furthermore, a positive correlation was observed between sugars and total anthocyanins and carotenoids.

Table 3. The intensity of the correlations between fruit production, fruit weight, total sugar (TSC), total polyphenols (TPC), total flavonoids (TFC), total anthocyanins (TAC), lycopene and β-carotene contents, and DPPH radical scavenging activity (RSA%) in *Cornus mas* L. fruits.

Pearson Correlation	Fruit Production	Fruit Weight	TSC	TPC	TFC	TAC	Lycopene	β-Carotene
Fruit weight	0.702 **	1						
TSC	−0.899 **	−0.922 **	1					
TPC	−0.530 *	−0.119	0.446	1				
TFC	−0.919 **	−0.691 **	−0.893 **	0.730 **	1			
TAC	−0.815 **	−0.667 **	0.704 **	0.075	0.690 **	1		
Lycopene	0.625 *	0.876 **	−0.736 **	0.251	−0.468	−0.819 **	1	
β-carotene	0.657 **	0.941 **	−0.919 **	−0.326	−0.711 **	−0.437	0.672 **	1
% RSA	−0.571 *	−0.116	0.392	0.822 **	0.762 **	0.422	0.071	−0.145

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

A particularly interesting result is the strong correlations between sugars and bioactive compounds. Total sugar content (TSC) shows a significant negative correlation with both TFC (r = −0.893 **) and β-carotene (r = −0.919 **), suggesting that the accumulation of carbohydrates may occur at the expense of phenolic compounds and carotenoids. In contrast, the positive correlation between TSC and TAC (r = 0.704 **) suggests that anthocyanins may be associated with the ripening process, during which fruits accumulate sugars and red pigments. Carotenoids (lycopene and β-carotene) show a distinct behaviour. Fruit weight is strongly correlated with their contents (r = 0.876 ** for lycopene and r = 0.941 ** for β-carotene), suggesting that larger fruits have a greater capacity to accumulate carotenoid pigments. Conversely, anthocyanins (TAC) exhibit a strong negative correlation with lycopene (r = −0.819 **) and β-carotene (r = −0.437), reflecting biochemical competition between carotenoid and anthocyanin synthesis pathways specific to stages of fruit maturation and cellular differentiation. A key parameter for characterizing the nutritional value of fruits is the antioxidant capacity (RSA%), which shows a significant positive correlation with TPC (r = 0.822 **) and TFC (r = 0.762 **). This confirms the dominant role of polyphenols and flavonoids in the antioxidant activity of *Cornus mas* L. fruits. The observation is consistent with specialized literature [15,44,49,52], which emphasizes the major contribution of phenolic compounds to the neutralization of free radicals.

Figure 1 shows the FTIR spectra of cornelian cherry powder, which exhibits three characteristic regions: 3600–2500 cm^{-1}, 1800–1300 cm^{-1}, and 1250–700 cm^{-1}. Table 4 shows the frequencies and assignments of the bands observed in the vibrational spectra for the five cornelian cherry samples. The bands in the 3400–3000 cm^{-1} range are generally associated with various hydroxyl (OH) stretching vibrations. The 3000–2900 cm^{-1} range corresponds to the symmetric and asymmetric stretching vibrations of the C–H band and the stretching vibration of the N–H band, respectively, which are associated with both the alkyl and aromatic groups [30,57].

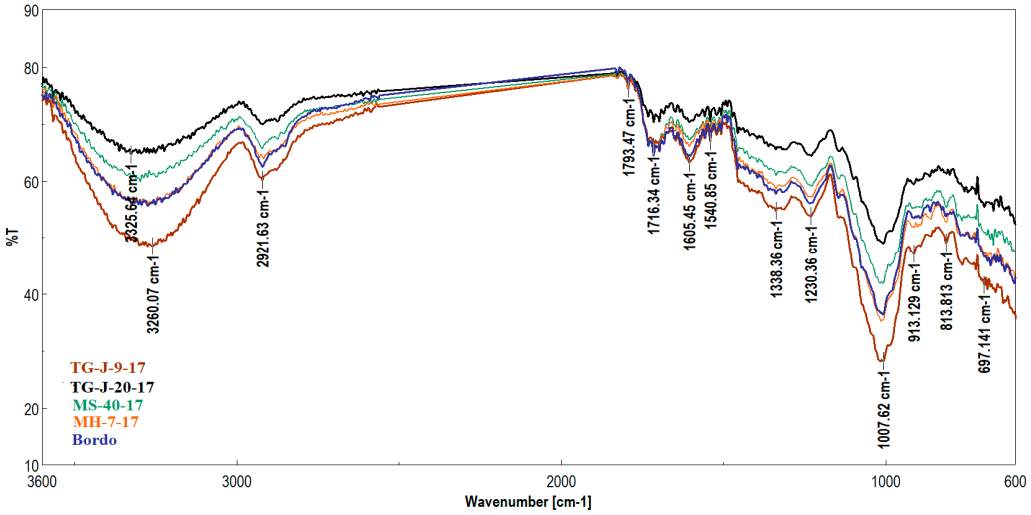


Figure 1. FTIR spectra of cornelian cherry powders.

Table 4. Main bands in the ATR-FTIR spectra of dry Cornelian cherry.

TG-J-20-17	TG-J-9-17	MS-40-17	MH-7-17	Bordo	Assignation
3326	3260	3297	3324	3274	O–H stretching (water, phenolics, anthocyanins)—broad band
2919	2921	2921	2917	2920	Aliphatic C–H stretching (CH_2/CH_3)—lipids/aliphatic components
1732 1716	1716	1716	1716	1716 1698	C=O stretching (ester or carboxylic acid)—consistent with phenolic esters (e.g., chlorogenic acid)
1646	1646	1646	1651	1646	C=C aromatic/conjugated carbonyl vibrations (phenolic acids, flavonoids) [58] Amide I (disordered structure-non-hydrogen bonded) [57,59]
1605	1605	1605	1606	1607	Aromatic C=C stretching (phenolic acids, flavonoids) [58]
1558 1541 1522 1507	1540 1521 1508	1558 1541 1521 1507	1558 1540 1521 1507	1558 1540 1521 1508	Aromatic skeletal vibrations/conjugated systems (flavonoids) [58] Amide II [30]
1456	1453	1453	1456	1488	CH bending; phenolic or aliphatic contributions
1311	1338	1338	1338	1338	C–O stretching (phenolic)/C–O–C glycosidic bonds (anthocyanin glycosides) [58]
1230	1230	1228	1238	1234	C–O stretching (phenolic)/C–O–C glycosidic bonds (anthocyanin glycosides)
1007	1007	1008	1014	1008	Strong C–O and C–C stretching (sugars, glycosides, pectin)—major polysaccharide band [60]
803 746 732 668	814 764 723 697	812 764 689 668	814 737 722 669	895 863 723 677	Out-of-plane aromatic C–H bending (aromatic ring substitution patterns; fingerprint region)

All wavenumber values are in cm^{-1}.

In the second region, absorption bands for carboxyl and ester groups can be found between 1640 and 1720 cm^{-1} [37,61]. The presence of amide I (stretch vibrations of C=O and C-N groups) and amid II (mainly from N-H bending) at absorbing wavelengths between 1700 and 1500 cm^{-1} and 1500–1300 cm^{-1} proves the presence of the protein. The variation in the spectral area between 1400 and 1100 cm^{-1} is attributable to the bending vibrational modes of OCH, CCH, and COH in carbohydrates. The variation in the spectral area between 1400 and 1100 cm^{-1} is attributable to the bending vibrational modes of OCH, CCH, and COH in carbohydrates [62,63]. Phenolic compounds had peaks between 1600 and 900 cm^{-1}. The observed bond at 1640 cm^{-1} is mostly due to the vibrational modes of C-C bonds in phenolic compounds [64]. In the third region, C-O-H bonds and C-O, C-O-C glycosidic bonds are present between 1250 and 700 cm^{-1} [30,60]. The spectral area below 900 cm^{-1} represents the fingerprint of the crystal field, indicating conformational changes in the material [59].

As can be seen in Figure 1, no significant differences were observed between the FTIR spectra of the analysed cornelian cherry powder samples. However, sample discrimination was possible using chemometric analysis. The 1300–1180 cm^{-1} region produced good results for discriminating between the powders. The first three principal components (PCs) accounted for 96% of the total variance among the samples (PC1 = 73%, PC2 = 13%, and PC3 = 3%). This indicates that these three components were sufficient to provide good group separation (Figure S1). This region encompasses the area characteristic of polyphenols and phenolic compounds (C–O, aromatic C–C bands, phenolic ring vibrations, etc.), which is often favoured for carbohydrate spectral analysis in IR spectroscopy. TG-J-9-17 was separated from the other cornelian cherry samples. The PC1–PC2 model revealed clear separation among the analysed samples. Samples MS-40-17 and MH-7-17 clustered closely together, indicating highly similar spectral profiles and therefore comparable phenolic fingerprints. In contrast, 'Bordo' and TG-J-20-17 were located on the positive side of PC1 and were separated from the first group, suggesting differences in phenolic composition or concentration. Sample TG-J-9-17 occupied the most distant position relative to all others, reflecting its distinct chemical profile within this spectral interval.

The PC1–PC3 projection provided additional discrimination not visible in the PC1–PC2 space. Sample 'Bordo' remained clearly separated along PC3, suggesting unique structural or concentration differences in phenolic-associated absorption bands. Meanwhile, MS-40-17 and MH-7-17 again grouped closely, reinforcing their chemical similarity. Sample TG-J-20-17 occupied a distinct quadrant relative to TG-J-9-17, confirming that the two samples differ significantly in their FTIR signatures when the third principal component is considered. The distribution of samples along PC3 highlights subtle but relevant spectral variations that complement the separation seen in PC1–PC2. PCA was applied as an exploratory chemometric tool to visualize spectral similarity patterns, rather than for predictive statistical modelling.

Hierarchical cluster analysis (HCA) in Figure 2, performed on the same spectral interval, further supported the PCA observations by grouping the samples according to their overall spectral similarity. Hierarchical clustering using complete linkage and Euclidean distance on the same pre-processed data produces a dendrogram that is consistent with the PCA interpretation. TG-J-9-17, MS-40-17, and TG-J-20-17 form a tighter subcluster, while MH-7-17 and 'Bordo' group separately and merge with the other cluster at a larger relative distance. This concordance between PCA and clustering demonstrates robust sample differentiation in the phenolic spectral region, while small differences between the two methods reflect that PCA projects the most dominant variance onto a low-dimensional subspace (PC1–PC2), whereas clustering uses full-dimensional distances and can be sensitive to minor spectral differences retained outside PC1–PC2.

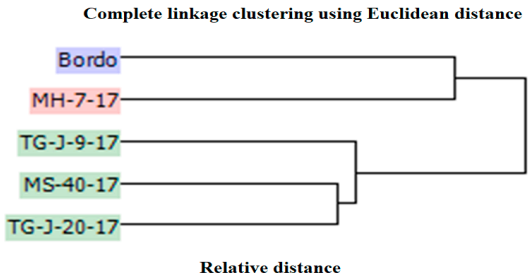


Figure 2. HCA dendrogram of FTIR spectra from cornelian cherry samples.

The PCA and HCA analyses focused on the 1380–1000 cm^{-1} region because this spectral interval contains the most informative vibrational bands of polyphenols and carbohydrate-related functional groups. These groups exhibit the greatest compositional variability among genotypes, maximising spectral discrimination.

4. Conclusions

A comparison of the agronomic and functional characteristics of the five *Cornus mas* L. genotypes revealed significant differences. The 'Bordo' cultivar demonstrated the best agronomic performance, with the highest average berry weight (3.07 g) and productivity (8.24 kg per plant). Its larger fruit size and high productivity make it ideal for large-scale cultivation and advantageous for sales in the fresh produce market, where larger fruits tend to be preferred by consumers. The MH-7-17 selection followed closely behind with an average yield of 7.37 kg per plant. At the other end of the spectrum, the TG-J-20-17 selection produced the lowest yield at 3.93 kg per plant.

The high levels of polyphenols, flavonoids, anthocyanins, carotenoids and sugars found in certain genotypes make them particularly well-suited to specific industrial applications. Notably, the 'Bordo' cultivar has a high lycopene content of 0.88 mg/100 g and a high β-carotene content of 2.47 mg/100 g, as well as a low sugar content of 7.33 g/100 g GluE, making it suitable for consumers requiring a reduced sugar intake. The TG-J-9-17 selection has the highest polyphenol, flavonoid and RSA% content, indicating good antioxidant potential. It is therefore ideal for use in the production of functional foods such as juices, jams, syrups and antioxidant-enriched yoghurts. Despite its lower yield and smaller fruit, the TG-J-20-17 selection has high levels of anthocyanins, making it valuable for specialised markets focused on health benefits and nutraceutical products. The anthocyanin-rich powders from this selection can replace synthetic dyes in soft drinks and confectionery and can be used in anti-ageing products due to their protective properties against oxidative stress. Furthermore, given their high flavonoid content, the TG-J-20-17 and TG-J-9-17 selections could be used to develop pharmaceutical preparations of anti-inflammatory and neuroprotective agents. The present results provide a scientific basis for future studies focusing on the utilisation of *Cornus mas* L. fruit as functional food ingredients. Previous research has demonstrated the successful incorporation of fruit pomace into bakery products to enhance their nutritional value [41]. The rapid spectroscopic-chemometric approach proposed in this study could therefore help to select and assess the quality of suitable raw materials for such applications, thereby promoting sustainable, circular food processing strategies.

The significant effect of genotype on the content of bioactive compounds in *Cornus mas* fruits indicates that genetics plays a key role in determining the concentration of these compounds. Understanding genetic factors is therefore essential for developing specific breeding programmes aimed at improving crops and creating varieties with enhanced nutritional properties and health-promoting attributes. This knowledge could contribute to sustainable agriculture and support the production of *Cornus mas* fruits that align with consumer preferences and health trends. Considering both agronomic performance and

the content of bioactive compounds helps us to identify the most versatile and high-quality *Cornus mas* L. genotypes for various consumer and industrial needs.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app16021007/s1, Figure S1: Two-dimensional scores obtained from the principal component analysis (PCA) of cornelian cherry FTIR spectra for the first two PCs (a) and PC3 versus PC1 (b); Table S1: One Way ANOVA results for berry weight, fruit production, total sugar content (TSC), total phenolic content (TPC), total tannin content (TTC), total flavonoid content (TFC), total anthocyanin content (TAC), lycopene content, β-carotene content, and radical scavenging activity (RSA) determined for *Cornus mas* L. genotypes.

Author Contributions: Conceptualization, L.E.V. and O.H.; methodology, C.M.T. and L.E.V.; software, C.M.T., L.E.V. and O.H.; validation, C.M.T., L.E.V. and O.H.; formal analysis, O.H.; investigation, C.M.T. and L.E.V.; resources, L.E.V.; writing—original draft preparation, O.H.; writing—review and editing, C.M.T. and L.E.V.; supervision, L.E.V. and M.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding authors.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Borroto Fernandez, E.G.; Khayatzadeh, N.; Mészáros, G.; Fink, S.; Hanzer, V.; Sölkner, J.; Laimer, M. Genetic Evaluation of a Wildtype Population of *Cornus mas* Accessions in Austria. *Diversity* **2023**, *15*, 1031. [CrossRef]
2. Hosseinpour-Jaghdani, F.; Shomali, T.; Gholipour-Shahraki, S.; Rahimi-Madiseh, M.; Rafieian-Kopaei, M. *Cornus mas*: A review on traditional uses and pharmacological properties. *J. Complement. Integr. Med.* **2017**, *14*, 20160137. [CrossRef]
3. Çevik, C.K.; Taban Akça, K.; Süntar, İ. Cornelian Cherry (*Cornus mas* L.): Insight into its Phytochemistry and Bioactivity. *J. Res. Pharm.* **2025**, *26*, 1493–1512. [CrossRef]
4. Czerwińska, M.E.; Melzig, M.F. *Cornus mas* and *Cornus Officinalis*-Analogies and Differences of Two Medicinal Plants Traditionally Used. *Front. Pharmacol.* **2018**, *9*, 894. [CrossRef]
5. Enache, I.M.; Stănciuc, N.; Vasile, A.M.; Dinică, R.M.; Țupu, E.; Vizireanu, C. *Cornus mas*: From Plant Taxonomy and Distribution Area to Highly Valorization of Phytochemicals by Microencapsulation in Biopolymeric Matrices Containing Probiotics. *Plants* **2025**, *14*, 3298. [CrossRef] [PubMed]
6. Frumuzachi, O.; Nicolescu, A.; Babotă, M.; Mocan, A.; Sisea, C.R.; Hera, O.; Sturzeanu, M.; Rohn, S.; Lucini, L.; Crișan, G.; et al. D-Optimal Design-Based Ultrasound-Assisted Extraction Optimization and Extensive Bio-Structural Analysis of Phenolic Compounds from Romanian Cornelian Cherry (*Cornus mas* L.) Genotypes. *Food Bioprocess Technol.* **2025**, *18*, 7915–7932. [CrossRef]
7. Lazăr, A.; Benedek, A.M.; Sîrbu, I. Small Mammals in Forests of Romania: Habitat Type Use and Additive Diversity Partitioning. *Forests* **2021**, *12*, 1107. [CrossRef]
8. Skender, A.; Hadžiabulić, S.; Ercisli, S.; Hasanbegović, J.; Dedić, S.; Almeer, R.; Sayed, A.A.; Ullah, R.; Assouguem, A. Morphological and Biochemical Properties in Fruits of Naturally Grown Cornelian Cherry (*Cornus mas* L.) Genotypes in Northwest Bosnia and Herzegovina. *Sustainability* **2022**, *14*, 4579. [CrossRef]
9. Moskalets, T.; Bordiug, N.; Pelekhatyi, V.; Ishchuk, O.; Svitelskyi, M. Ecological Aspects of the Comparative Study of *Cornus mas* L. Genotypes According to Morphological Characteristics of the Fruits, the Content of Functional Groups of Biochemical Substances and Suitability for Healthy Food Production. *Ecol. Eng. Environ. Technol.* **2024**, *25*, 158–171. [CrossRef]
10. Seeram, N.P.; Schutzki, R.; Chandra, A.; Nair, M.G. Characterization, quantification, and bioactivities of anthocyanins in *Cornus* species. *J. Agric. Food Chem.* **2002**, *50*, 2519–2523. [CrossRef]
11. Aurori, M.; Niculae, M.; Hanganu, D.; Pall, E.; Cenariu, M.; Vodnar, D.C.; Bunea, A.; Fiț, N.; Andrei, S. Phytochemical Profile, Antioxidant, Antimicrobial and Cytoprotective Effects of Cornelian Cherry (*Cornus mas* L.) Fruit Extracts. *Pharmaceuticals* **2023**, *16*, 420. [CrossRef]

12. Jahanban, A.; Jahanban, R.; Jamei, R.; Jahanban, A. Morphology and physicochemical properties of 40 genotypes of almond (*Amygdalus communis* L.) fruits. *Eur. J. Exp. Biol.* **2012**, *2*, 2456–2464.
13. Szczepaniak, O.M.; Kobus-Cisowska, J.; Kusek, W.; Przeor, M. Functional properties of Cornelian cherry (*Cornus mas* L.): A comprehensive review. *Eur. Food Res. Technol.* **2019**, *245*, 2071–2087. [CrossRef]
14. Jurikova, T.; Skowronkova, N.; Zvonkova, M.; Orsavova, J.; Ercisli, S.; Dokoupil, L.; Fatrcova-Sramkova, K.; Adamkova, A.; Mlcek, J. Polyphenolic spectrum of cornelian cherry fruits and their health-promoting effect. *Open Life Sci.* **2025**, *20*, 20251117. [CrossRef] [PubMed]
15. Cosmulescu, S.N.; Trandafir, I.; Cornescu, F. Antioxidant capacity, total phenols, total flavonoids and colour component of cornelian cherry (*Cornus mas* L.) wild genotypes. *Not. Bot. Horti Agrobot. Cluj-Napoca* **2019**, *47*, 390–394. [CrossRef]
16. Pantelidis, G.E.; Vasilakakis, M.; Manganaris, G.A.; Diamantidis, G. Antioxidant capacity, phenol, anthocyanin and ascorbic acid contents in raspberries, blackberries, red currants, gooseberries and Cornelian cherries. *Food Chem.* **2007**, *102*, 777–783. [CrossRef]
17. Szot, I.; Łysiak, G.P.; Sosnowska, B.; Chojdak-Łukasiewicz, J. Health-Promoting Properties of Anthocyanins from Cornelian Cherry (*Cornus mas* L.) Fruits. *Molecules* **2024**, *29*, 449. [CrossRef] [PubMed]
18. Dinda, B.; Kyriakopoulos, A.M.; Dinda, S.; Zoumpourlis, V.; Thomaidis, N.S.; Velegraki, A.; Markopoulos, C.; Dinda, M. *Cornus mas* L. (cornelian cherry), an important European and Asian traditional food and medicine: Ethnomedicine, phytochemistry and pharmacology for its commercial utilization in drug industry. *J. Ethnopharmacol.* **2016**, *193*, 670–690. [CrossRef]
19. Guo, L.; Qiao, J.; Huo, J.; Rupasinghe, H.P.V. Plant iridoids: Chemistry, dietary sources and potential health benefits. *Food Chem. X* **2025**, *27*, 102491. [CrossRef]
20. Stachniuk, A.; Szmagara, A.; Stefaniak, E.A. Spectrophotometric Assessment of the Differences Between Total Nitrate/Nitrite Contents in Peel and Flesh of Cucumbers. *Food Anal. Methods* **2018**, *11*, 2969–2977. [CrossRef]
21. Ajebe, E.G.; Bahiru, T.B. Spectrophotometric determination of nitrite and nitrate in some selected vegetables cultivated in Adami Tulu Judo Kombolicha district farms, Ethiopia. *J. Anal. Bioanal. Tech.* **2018**, *9*, 410. [CrossRef]
22. Namdev, P.S.; Patel, R. Vitamin A and E quantification using spectrophotometric methods. *J. Reatt. Ther. Develop. Diversit.* **2023**, *6*, 534–551. [CrossRef]
23. Li, X.; Lv, H.; Luo, W.; Yang, W.; Kong, L.; Zhu, Q.; Zeng, L. Recent advances in detection techniques for vitamin analysis: A comprehensive review. *Food Chem. X* **2025**, *26*, 102226. [CrossRef]
24. Tirado-Kulieva, V.A.; Hernández-Martínez, E.; Suomela, J.P. Non-destructive assessment of vitamin C in foods: A review of the main findings and limitations of vibrational spectroscopic techniques. *Eur. Food Res. Technol.* **2022**, *248*, 2185–2195. [CrossRef]
25. Gauillard, F.; Richard-Forget, F.; Nicolas, J. New spectrophotometric assay for polyphenol oxidase activity. *Anal. Biochem.* **1993**, *215*, 59–65. [CrossRef]
26. Sadananda, C.; Singha, L.B.; Tripathi, O.P.; Dilip, S.; Premkumar, K.; Lulloo, P. Quantification of enzymatic antioxidants (catalase and peroxidase) and non-enzymatic antioxidants (ascorbic acid and chlorogenic acid) in the tender shoots of seven bamboo species and their products, found in Arunachal Pradesh, India. *Adv. Bamboo Sci.* **2023**, *5*, 100048. [CrossRef]
27. Kurek, M.A.; Aktaş, H.; Pokorski, P.; Pogorzelska-Nowicka, E.; Custodio-Mendoza, J.A. A comprehensive review of analytical approaches for carotenoids assessment in plant-based foods: Advances, applications, and future directions. *Appl. Sci.* **2025**, *15*, 3506. [CrossRef]
28. Kotecha, J.L.; Ram, V.R. Extraction and spectrophotometric determination of chlorophyll content and carotenoids from *Cocos nucifera* L. leaf using various solvents in Saurashtra region. *Int. J. Plant Environ.* **2023**, *9*, 364–368. [CrossRef]
29. Sumanta, N.; Haque, C.I.; Nishika, J.; Suprakash, R. Spectrophotometric analysis of chlorophylls and carotenoids from commonly grown fern species by using various extracting solvents. *Res. J. Chem. Sci.* **2014**, *4*, 63–69.
30. Stamin, F.D.; Vijan, L.E.; Topală, C.M.; Cosmulescu, S.N. The Influence of Genotype, Environmental Factors, and Location on the Nutraceutical Profile of *Rosa canina* L. Fruits. *Agronomy* **2024**, *14*, 2847. [CrossRef]
31. Giura, S.; Botu, M.; Vulpe, M.; Vijan, L.E.; Mitrea, R. Evolution of the polyphenols, flavonoids, and tannins content in walnut leaves and green walnut husk during growing season. *Not. Bot. Horti Agrobot. Cluj-Napoca* **2019**, *47*, 1264–1271. [CrossRef]
32. Tudor-Radu, M.; Vijan, L.E.; Tudor-Radu, C.M.; Tița, I.; Sima, R.; Mitrea, R. Assessment of ascorbic acid, polyphenols, flavonoids, anthocyanins and carotenoids content in tomato fruits. *Not. Bot. Horti Agrobot. Cluj-Napoca* **2016**, *44*, 477–483. [CrossRef]
33. Munteanu, A.L.; Vijan, L.E.; Topală, C.M.; Mitrea, R. Influence of the phytosanitary status, cultivar, and harvest time on the phenolic, chlorophyll, and alkaloid content of *Rosa* sp. leaves. *Horticulturae* **2023**, *9*, 1169. [CrossRef]
34. Falcioni, R.; Gonçalves, J.V.F.; de Oliveira, K.M.; de Oliveira, C.A.; Reis, A.S.; Crusiol, L.G.T.; Furlanetto, R.H.; Antunes, W.C.; Cezar, E.; de Oliveira, R.B. Chemometric analysis for the prediction of biochemical compounds in leaves using UV-VIS-NIR-SWIR hyperspectroscopy. *Plants* **2023**, *12*, 3424. [CrossRef] [PubMed]
35. Wu, S.; Liu, Y.; Fan, X.; Shen, Y.; Qu, H. Trends and new process analytical technologies in pharmaceutical manufacturing. *Int. J. Pharm.* **2025**, *682*, 125957. [CrossRef]
36. Casian, T.; Nagy, B.; Kovács, B.; Galata, D.L.; Hirsch, E.; Farkas, A. Challenges and opportunities of implementing data fusion in process analytical technology-a review. *Molecules* **2022**, *27*, 4846. [CrossRef]

37. Topală, C.; Rusea, I. Analysis of leaves using FTIR spectroscopy and Principal Component Analysis. Discrimination of different plant samples. *Curr. Trends Nat. Sci.* **2018**, *7*, 286–291.
38. Topală, C.M.; Tătaru, L.D. ATR-FTIR spectroscopy coupled with chemical and chemometric analysis to distinguish between some sweet wines. *Rev. Chim.* **2019**, *70*, 2355–2361. [CrossRef]
39. Topală, C.M.; Vîjan, L.E.; Giura, S.; Botu, M. Attenuated total reflection Fourier transform infrared (ATR-FTIR): A method for the biochemical study of walnut leaves. *Curr. Trends Nat. Sci.* **2020**, *9*, 266–272. [CrossRef]
40. Vîjan, L.E.; Mazilu, I.C.; Enache, C.; Enache, S.; Topală, C.M. Botanical origin influence on some honey physicochemical characteristics and antioxidant properties. *Foods* **2023**, *12*, 2134. [CrossRef]
41. Mandache, M.B.; Topală, C.M.; Vijan, L.E.; Cosmulescu, S. Enhancing biscuit nutritional value through apple and sour cherry pomace fortification. *Appl. Sci.* **2025**, *15*, 11823. [CrossRef]
42. ICDP. Available online: https://icdp.ro/en/cercetare/arbusti-fructiferi-si-capsun/ameliorarea-genetica-a-soiurilor/bordo/ (accessed on 2 November 2025).
43. Hassanpour, H.; Hamidoghli, Y.; Samizadeh, H. Some fruit characteristics of iranian cornelian cherries (*Cornus mas* L.). *Not. Bot. Horti Agrobot. Cluj-Napoca* **2012**, *40*, 247–252. [CrossRef]
44. Kazimierski, M.; Regula, J.; Molska, M. Cornelian cherry (*Cornus mas* L.)—Characteristics, nutritional and pro-health properties. *Acta Sci. Pol. Technol. Aliment.* **2019**, *18*, 5–12. [CrossRef]
45. Klymenko, S.; Ilyinska, A. The new earliest cultivar of cornelian cherry (*Cornus mas* L.). *Plant Introd.* **2023**, *97/98*, 46–60. [CrossRef]
46. Dokoupil, L.; Řezníček, V. Production and use of the Cornelian cherry—*Cornus mas* L. *Acta Univ. Agric. Silvic. Mendel. Brun.* **2012**, *60*, 49–58. [CrossRef]
47. Klimenko, S. The cornelian cherry (*Cornus mas* L.): Collection, preservation, and utilization of genetic resources. *J. Fruit. Ornam. Plant Res.* **2004**, *12*, 93–98.
48. Tural, S.; Koca, I. Physico-chemical and antioxidant properties of cornelian cherry fruits (*Cornus mas* L.) grown in Turkey. *Sci. Hortic.* **2008**, *116*, 362–366. [CrossRef]
49. Güzel, N. Biometric and physico-chemical properties of cornelian cherry (*Cornus mas* L.) grown in Çorum, Turkey. *Akad. Gıda* **2021**, *19*, 373–380. [CrossRef]
50. Kucharska, A.Z.; Sokół-Łętowska, A.; Piórecki, N. Morphological, physical and chemical, and antioxidant profiles of polish cultivars of cornelian cherry fruit (*Cornus mas* L.). *Zywnosc Nauka. Technologia. Jakosc* **2011**, *3*, 78–89.
51. Bijelić, S.; Gološin, B.; Ninić-Todorović, J.; Cerović, S.; Popović, B. Physicochemical fruit characteristics of cornelian cherry (*Cornus mas* L.) genotypes from Serbia. *HortScience* **2011**, *46*, 849–853. [CrossRef]
52. Hassanpour, H.; Yousef, H.; Jafar, H.; Mohammad, A. Antioxidant capacity and phytochemical properties of cornelian cherry (*Cornus mas* L.) genotypes in Iran. *Sci. Hortic.* **2011**, *129*, 459–463. [CrossRef]
53. Antoniewska-Krzeska, A.; Ivanišová, E.; Klymenko, S.; Bieniek, A.; Fatrcová-Šramková, K.; Brindza, J. Nutrients content and composition in different morphological parts of Cornelian cherry (*Cornus mas* L.). *Agrobiodiversity Improv. Nutr. Health Life Qual.* **2022**, *6*, 1–10. [CrossRef]
54. Herms, D.A.; Mattson, W.J. The dilemma of plants: To grow or defend. *Q. Rev. Biol.* **1992**, *67*, 283–335. [CrossRef]
55. Roch, L.; Prigent, S.; Klose, H.; Cakpo, C.B.; Beauvoit, B.; Deborde, C.; Fouillen, L.; van Delft, P.; Jacob, D.; Usadel, B.; et al. Biomass composition explains fruit relative growth rate and discriminates climacteric from non-climacteric species. *J. Exp. Bot.* **2020**, *71*, 5823–5836. [CrossRef]
56. Park, C.H.; Sathasivam, R.; Kim, T.J.; Park, B.B.; Kim, J.K.; Park, S.U. Metabolic profiling and secondary metabolite accumulation during fruit development of *Cornus officinalis* Sieb. et Zucc. *Ind. Crops Prod.* **2022**, *189*, 115779. [CrossRef]
57. Durgawati; Balasubramanian, P.; Sutar, P.P. Development of a novel non-water infrared refractance window drying method for Malabar spinach: Optimization of process parameters using drying kinetics, mass transfer, and powder characterization. *Dry. Technol.* **2023**, *41*, 1620–1635. [CrossRef]
58. Movasaghi, Z.; Rehman, S.; ur Rehman, I. Fourier Transform Infrared (FTIR) Spectroscopy of Biological Tissues. *Appl. Spectrosc. Rev.* **2008**, *43*, 134–179. [CrossRef]
59. Kaba, B.; Yıkılkan, Y.; Pashazadeh, H.; Redha, A.A.; Koca, I. Production of cornelian cherry (*Cornus mas* L.) pulp powder by foam-mat drying: Analysis of physicochemical and antioxidant properties. *Biomass Convers. Biorefinery* **2025**, *15*, 3663–3678. [CrossRef]
60. Moniri, H.; Farahmandfar, R.; Motamedzadegan, A. Investigation of hot air and foam-mat dried cress seed gum by FT-IR, zeta potential, steady shear viscosity, dynamic oscillatory behavior, and other physical properties. *Food Sci. Nutr.* **2020**, *8*, 2143–2155. [CrossRef]
61. Pancerz, M.; Ptaszek, A.; Sofińska, K.; Barbasz, J.; Szlachcic, P.; Kucharek, M.; Łukasiewicz, M. Colligative and hydrodynamic properties of aqueous solutions of pectin from cornelian cherry and commercial apple pectin. *Food Hydrocoll.* **2019**, *89*, 406–415. [CrossRef]

62. Athmaselvi, K.A.; Kumar, C.; Balasubramanian, M.; Roy, I. Thermal, structural, and physical properties of freeze dried tropical fruit powder. *J. Food Process.* **2014**, *2014*, 524705. [CrossRef]
63. Kumar, P.S.; Keran, D.A.; Pushpavalli, S.; Shiva, K.N.; Uma, S. Effect of cellulose and gum derivatives on physicochemical, microstructural and prebiotic properties of foam-mat dried red banana powder. *Int. J. Biol. Macromol.* **2022**, *218*, 44–56. [CrossRef] [PubMed]
64. Sarabandi, K.; Jafari, S.M.; Mahoonak, A.S.; Mohammadi, A. Application of gum Arabic and maltodextrin for encapsulation of eggplant peel extract as a natural antioxidant and color source. *Int. J. Biol. Macromol.* **2019**, *140*, 59–68. [CrossRef] [PubMed]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.