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Cold Screw Pressing Followed by Lyophilisation Enhances Antioxidant Compound Retention in Rosehip Waste Powder

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Abstract

Processing rosehips generates substantial solid waste that retains valuable bioactive compounds. This study evaluated the effects of different treatments on the composition, phenolic and flavonoid contents, and antioxidant capacity of powders derived from rosehip waste. Rosehips were processed into purée by cold screw pressing or boiling, yielding raw and boiled processing waste fractions (RW and BW). These fractions were then dehydrated by hot-air drying or lyophilisation to obtain RWd, RWl, BWd, and BWl. Additionally, a previous cold screw pressing step was applied to the boiled processing waste, producing BWpd and BWpl. Cold screw pressing increased phenolic and flavonoid levels and enhanced the antioxidant capacity of the resulting waste compared with traditional boiling. The lyophilised powder derived from raw processing waste exhibited the highest total phenolic content (TPC, 27.16 mg GAE/g), total flavonoid content (TFC, 20.35 mg QUE/g), and Trolox equivalent antioxidant capacity by ABTS and DPPH (TEAC-ABTS, 89.13 µmol TE/g; TEAC-DPPH, 163.99 µmol TE/g), although at higher processing costs. As hot-air drying achieved comparable levels for TPC (20.01 mg GAE/g), TFC (19.53 mg QUE/g), TEAC-ABTS (58.01 µmol TE/g), and TEAC-DPPH (150.01 µmol TE/g), it may represent a more economical alternative to lyophilisation. These findings demonstrate the potential of rosehip-processing waste as a sustainable raw material for the development of functional food ingredients.

Keywords: food waste valorisation; functional food ingredient; phenolic compounds; flavonoid compounds; antioxidant capacity

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Academic Editors: Shogo Mori, Sylvie Garneau-Tsodikova and Adem Gharsallaoui

Received: 29 January 2026
Revised: 8 March 2026
Accepted: 10 March 2026
Published: 11 March 2026

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1. Introduction

The genus Rosa (Rosaceae) comprises nearly 200 species with approximately 20,000 cultivars, which are widely distributed across temperate and subtropical areas of Asia, Europe, Africa, and North America [1,2]. Among these, *Rosa canina* L. (dog rose) is one of the most widespread and resilient species, thriving under diverse pedoclimatic conditions, from sea level to high altitudes, including poor or rocky soils [3].

Botanically, rosehip is a pseudo-fruit (or pseudocarp) formed by an enlarged fleshy floral cup known as the hypanthium, which encloses multiple achenes, the true fruits containing single seeds [4,5]. This structure underlies its rich phytochemical composition, with the hypanthium particularly abundant in vitamin C, carotenoids, polyphenols, tocopherols, flavonoids, and anthocyanins [6,7]. Its seeds are rich in lipids, including polyunsaturated

fatty acids (mainly linoleic and α-linolenic acids), sterols, and tocopherols, highlighting their potential as functional ingredients [8,9]. Owing to this chemical composition, rosehip exhibits strong antioxidant, anti-inflammatory, immunomodulatory, antimicrobial, antidiabetic, and cardioprotective properties [10–12].

Most research to date has focused on rosehip fruits. However, the solid waste generated during their processing—although still containing valuable bioactive compounds—has received comparatively little attention. Approximately 11,000 tonnes of rosehip fruits are processed annually in Europe, with the main production centres located in Romania, Bulgaria, Sweden, and Hungary [13]. In Romania, these fruits are predominantly processed into rosehip purée. During the mashing operation alone, approximately 30% of the raw material is lost as waste [14]. Therefore, identifying strategies to valorise this processing waste is essential, not only to reduce environmental pollution but also to facilitate innovative applications in the food and feed industries. Our earlier work revealed, for the first time, that rosehip-processing waste can be valorised as a powdered ingredient with techno-functional properties suitable for the food industry [15]. We also demonstrated that this powder can effectively enrich sausages and waffle cones with fibre, carotenoids, and polyphenols [16,17]. Similarly, a study on a powder prepared from *Rosa rugosa* pomace using microwave–vacuum drying reported successful enrichment of wheat pasta with polyphenols [18].

In recent years, there has been growing interest in innovative, non-thermal technologies for the processing and valorisation of fruit and vegetable by-products. Techniques such as pulsed electric field (PEF), cold plasma, and Ultrasonic-assisted extraction (UAE) have attracted attention for their ability to enhance the recovery and stability of bioactive compounds from plant materials, including rosehip waste. For example, PEF treatment has been shown to significantly improve the extraction yield of polyphenols, carotenoids, and other valuable phytochemicals from rosehip matrices and other by-products [19,20]. Likewise, cold plasma pretreatment has been shown to increase the phenolic and vitamin C content in rosehip-based ingredients [21]. Moreover, the UAE, particularly when combined with natural deep eutectic solvents, is effective for the recovery of polyphenols from rosehip seed waste [22]. However, the high cost of these technologies currently limits their industrial application for low-value food materials such as rosehip waste.

From an industrial perspective, rosehip waste powder may be produced using various fruit-processing and dehydration methods. However, current industrial practices are primarily optimised for purée or jam production rather than for preserving bioactive compounds in the waste fraction. Consequently, there is a clear need to identify the technological factors governing the retention of phenolics and flavonoids, along with their associated antioxidant capacity, in rosehip-processing waste.

The quality of rosehip waste powder is influenced by both the fruit-processing method and the drying technique applied to the resulting waste. Traditionally, rosehip jam is produced by boiling the fruit in tap water, then partially draining the liquid, and subsequently crushing, pressing, and squeezing the fruit to obtain a purée. This purée is typically incorporated at approximately 60% in the jam formulation, together with sugar, glucose–fructose syrup, pectin, and citric acid [15]. However, most phenolic and flavonoid compounds are relatively unstable at high temperatures [23] and may degrade during boiling. To overcome this limitation, rosehip purée can alternatively be prepared by cold pressing the fruits, as suggested by Borşa et al. [15].

Building on our previous findings that rosehip-processing waste is rich in bioactive compounds, the present study investigates how different methods of rosehip purée processing influence the phytochemical profile, energy content, and antioxidant potential of the resulting waste and its derived powders. Specifically, the study compares cold

screw pressing with traditional boiling of the fruits, followed by dehydration of the waste using hot-air drying or lyophilisation, with and without previous cold screw pressing of the boiled processing waste. Samples collected throughout rosehip fruit processing were subjected to comprehensive chemical analyses spanning all stages from raw material to final product.

To our knowledge, this study represents the first systematic integration of fruit-processing pathways with dehydration strategies to assess their combined effects on proximate composition, pH, phenolic and flavonoid contents, and antioxidant capacity of powders prepared from rosehip waste. By directly linking processing technology to bioactive compound retention, this research advances current knowledge and supports the sustainable industrial valorisation of this waste stream.

2. Materials and Methods

The rosehips (R) used in this study were *Rosa canina*, purchased from the Alba Forestry Directorate—ROMSILVA in October 2022. After acquisition, the fruit was divided into two batches, each assigned to a different processing method, and refrigerated overnight. One batch was sent to an authorised local manufacturer (Săvădisla, Romania) to produce traditional rosehip purée, which involved boiling the fruits in water. This process generated a solid waste referred to as BW (boiled processing waste). The second batch was processed into purée (Pr; 70.53% moisture content) using a modern cold screw pressing technique with a PU05 press machine (S.C. Jobs Ahead Group S.R.L., Bucharest, Romania), resulting in a solid material called RW (raw processing waste). The pressing was performed under continuous operation without external heating. The temperature increase during pressing resulted solely from mechanical friction and remained below 40 °C, thus maintaining cold-press extraction conditions. Pretreatment for both batches involved sorting and cleaning to eliminate spoiled or rotten items and physical impurities. The fruits were then washed with tap water, strained, air-dried, and weighed.

The two waste materials (BW and RW) were subjected to dehydration by hot-air drying and lyophilisation, with and without previous cold screw pressing of boiled processing waste, to produce rosehip powders. Hot-air drying was performed using a DEH-450 dehydrator (Biovita S.R.L., Cluj-Napoca, Romania), and lyophilisation was conducted using a LyoQuest -55 Plus freeze dryer (Azbil Telstar, Barcelona, Spain). Each dried waste sample was then ground using a Titan Mil 300 DuoClean grinder (Grupo Cecotec Innovaciones S.L., Valencia, Spain) until a finely ground powder (<10 μm) was obtained. The treatments applied to the two types of waste, as detailed in Figure 1, resulted in six ingredient powders: RWd, powder from raw processing waste subjected to hot-air drying; RWl, powder from raw processing waste subjected to lyophilisation; BWd, powder from boiled processing waste subjected to hot-air drying; BWl, powder from boiled processing waste subjected to lyophilisation; BWpd, powder from boiled processing waste subjected to hot-air drying after cold screw pressing; and BWpl, powder from boiled processing waste subjected to lyophilisation after cold screw pressing. Under the experimental conditions used in this study, the estimated production costs were approximately 3 EUR for hot-air-dried powders and 15 EUR for lyophilised powders, confirming the substantially higher economic burden associated with lyophilisation.

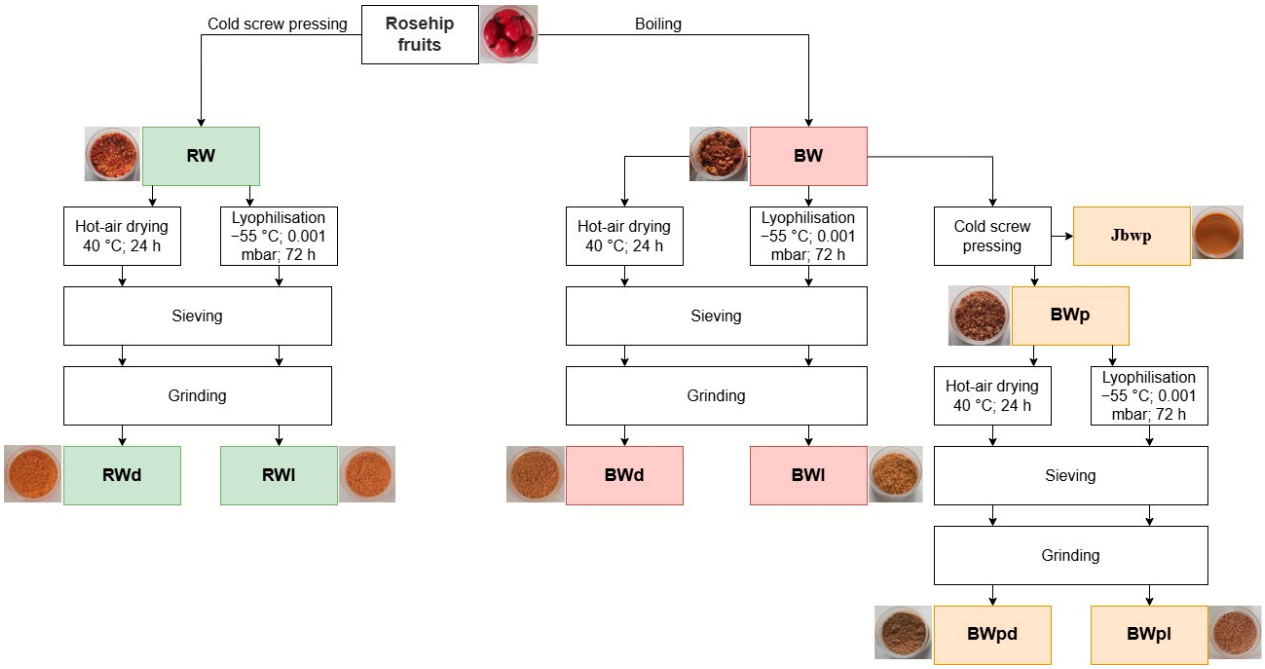


Figure 1. Flowchart of the production process for each rosehip waste powder.

All rosehip samples underwent the analyses described in the following sections.

2.1. Reagents and Solvents

The proximate composition analysis utilised the following solvents and reagents: anhydrous potassium sulphate, copper (II) sulphate pentahydrate, sodium hydroxide, pure boric acid, 0.1 N hydrochloric acid standard solution, pumice stone, petroleum ether with a boiling range of 40–60 °C (Chempur, Piekary Śląskie, Poland), sulfuric acid 98% (VWR Chemicals, Rosny-sous-Bois, France), and Tashiro's indicator solution (Fluka, Seelze, Germany).

Methanol from Honeywell/Riedel-de-Haën (Poland) was used to prepare the methanolic extracts.

Reagents used to measure total phenolic content included gallic acid, natriumcarbonat decahydrate (Carl Roth, Karlsruhe, Germany), and Folin–Ciocalteu's phenol reagent (Sigma-Aldrich, Saint Louis, MO, USA).

Methanol (Honeywell/Riedel-de-Haën, Seelze, Germany), sodium nitrite, aluminium chloride (S.C. Nordic Chemicals S.R.L., Cluj-Napoca, Romania), sodium hydroxide (Chempur, Piekary Śląskie, Poland), and quercetin (Sigma-Aldrich, Steinheim, Germany) were used to determine total flavonoid content.

Potassium peroxodisulphate (Merk, Darmstadt, Germany), 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) diammonium salt (Thermo Fisher, Kandel, Germany), (R)-(+)-6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Sigma-Aldrich, Saint Louis, MO, USA), and 2,2-diphenyl-1-picrylhydrazyl (Alfa Aesar, Kandel, Germany) were used to determine antioxidant capacity.

The HPLC-DAD-ESI/MS analysis of polyphenols employed glacial acetic acid (LC-MS grade), methanol (LC-MS grade) from Merck (Darmstadt, Germany), acetonitrile (LC-MS grade), and ultrapure water. Catechin was sourced from Supelco (Bellefonte, PA, USA), while rutin, cyanidin, gallic acid, and chlorogenic acid were obtained from Phytolab (Vestenbergsgreuth, Germany). Polyamide syringe filters (Chromafil Xtra PA 45/25) were supplied by Macherey-Nagel (Düren, Germany), and nitrogen was obtained from SIAD Romania s.r.l. (Bucharest, Romania).

2.2. Determination of Proximate Composition

The oven-drying method was used to determine the moisture content. A 2.0 g sample was dehydrated at 103 °C using a J.P. Selecta S.A. Digitheat oven (Barcelona, Spain) until mass constancy was attained. It was calculated using Equation (1):

$$Moisture\ content\ (\%) = \frac{w_1 - w_2}{w_1} \times 100, \quad (1)$$

where w_1 represents the sample's pre-drying weight (g), and w_2 represents the sample's post-drying weight (g).

Protein content was determined using the Kjeldahl method. A 0.25 g sample was mineralised with 15 g anhydrous potassium sulphate, 0.5 g copper (II) sulphate pentahydrate, and 20 mL concentrated sulfuric acid in a digestion tube using a heating digester (I step: 125 °C for 30 min; II step: 270 °C for 30 min; III step: 400 °C for 120 min) equipped with a recirculating water pump. The mineralised sample was diluted with 20 mL of distilled water and then alkalised with 90 mL of 33% (w/w) sodium hydroxide solution. Next, the alkaline digest was steam distilled in the presence of 25 mL of 4% (w/v) boric acid solution and several drops of Tashiro's indicator solution using a UDK 129 distillation system (VELP Scientifica S.R.L., Usmate Velate, Italy). The trapped ammonia was quantified by titration with a 0.1 N hydrochloric acid standard solution to pH 5.4 using an InoLab® Multi 9310 IDS digital multi-parameter (WTW, Weilheim, Germany). The titration volume was used to calculate (2) the sample's nitrogen content; protein content was subsequently estimated by multiplying this value by 6.25 [24].

$$Nitrogen\ content\ (\%) = 0.0014 \times (V_1 - V_0) \times \frac{100}{w}, \quad (2)$$

where 0.0014 represents the nitrogen amount (g) corresponding to 1 mL of 0.1 N HCl solution, V_1 represents the volume (mL) of 0.1 N HCl solution used to titrate the sample, V_0 represents the volume (mL) of 0.1 N HCl solution used to titrate the blank, and w represents the sample's weight.

Fat content was determined by weighing 1.0 g of the sample using an ABJ-220-4NM analytical balance (Kern & Sohn, Balingen, Germany) in a defatted filter paper bag, which was then placed into a porous cellulose extraction thimble. The cellulose thimble was inserted into an extraction cup filled with 80 mL of petroleum ether. The extraction cup was then positioned in a SER 148 solvent extractor (VELP Scientifica S.R.L., Usmate Velate, Italy). The following settings were used for fat extraction: a hot plate temperature of 110 °C, a boiling time of 30 min per sample immersion cycle, a sample rinse cycle time of 4 h, and a solvent evaporation and recycle time of 30 min.

The cup containing the extracted fat was dehydrated for 1 h at 103 °C in an electric oven. After drying, the fat-containing cup was cooled in a desiccator to room temperature and then weighed. This procedure was repeated at hourly intervals until mass constancy was attained. Fat content was then calculated using Equation (3):

$$Fat\ content\ (\%) = \frac{w_2}{w_1} \times 100, \quad (3)$$

where w_1 represents the sample's weight (g), and w_2 represents the fat's weight (g).

The ash was quantified by calcining the sample in a L3/11/B170 muffle furnace (Nabertherm GmbH, Bremen, Germany). A 3.0 g portion was weighed into a porcelain crucible using an analytical balance and subsequently heated for 12 h at 600 °C. After

cooling to room temperature in a desiccator, the sample was reweighed. The ash content was computed using Equation (4):

$$Ash\ content\ (\%) = \frac{w_2}{w_1} \times 100, \quad (4)$$

where w_1 represents the sample's weight before incineration (g), and w_2 represents the sample's weight after incineration (g).

Results were given as percentages (%) after each rosehip sample underwent three independent analyses.

The total carbohydrate content (%) in each sample was calculated by subtracting the combined percentages of moisture, protein, fat, and ash from 100 [25]. The energy content of each rosehip sample was computed with Equation (5), as Semeniuc et al. [26] described:

$$Energy\ content\ (\text{kcal}/100\ \text{g}) = 4 \times (g\ carbohydrate + g\ protein) + 9 \times (g\ fat) \quad (5)$$

The pH determination was performed by weighing 10.0 g of the sample into a 150 mL Berzelius flask using an analytical balance. Subsequently, 100 mL of distilled water was added, and the content was mixed with a glass rod for 30 s. After 30 min of undisturbed storage at room temperature, the mixture was filtered. The pH of the extract was measured using a digital multi-parameter metre.

Each sample was tested in triplicate for the proximate composition.

2.3. Preparation of Methanolic Extracts

A 0.5 g sample was mixed with 5 mL of a 70% (v/v) methanol-water solution for 1 min with a 6776-vortex mixer (Corning Life Sciences, Monterrey, Mexico). The mixture was then sonicated at 200 W and 45 kHz for 30 min in an USC 300 THD ultrasonic bath (Singapore, Malaysia). Subsequently, it was centrifuged at 8981× g (9000 rpm) for 10 min at 4 °C using a Universal 320 R (Andreas Hettich, Tuttlingen, Germany), and the supernatant was collected. Each extraction was performed in triplicate. Extracts were kept at −18 °C until analysis for total phenolic and flavonoid contents, antioxidant capacity, or chromatographic separation of polyphenols. Prior to chromatographic analysis, samples were filtered with polyamide syringe filters having a 0.45 µm pore size and a 25 mm diameter.

For each sample, the following analytical determinations were performed in triplicate using independently prepared extracts.

2.3.1. Determination of Total Phenolic Content

The procedure followed the method described by Michiu et al. [27]. An aliquot of 100 µL of the extract was introduced into a 16 mL glass bottle, which was sealed with a rubber stopper. Subsequently, 6 mL of distilled water, together with 0.5 mL of 2 N Folin–Ciocalteu's phenol reagent, was added, and the resulting mixture was vortexed (6776; Corning Life Sciences, Monterrey, Mexico). After 4 min, 1.5 mL of 0.71 M sodium carbonate solution was added, followed by 1.9 mL of distilled water; the mixture was then vortexed. The mixture was then kept in the dark at room temperature for 2 h. Its absorbance was measured at 750 nm relative to a blank using a double-beam UV-Vis spectrophotometer (UV-1900i; Shimadzu, Columbia, MD, USA). The blank, prepared with 70% (v/v) methanol, underwent the same procedures as the test sample. Gallic acid at levels from 0.25 to 1.25 mg/mL was used to construct the calibration curve. Results were calculated in mg gallic acid equivalents (GAE)/g sample.

2.3.2. Determination of Total Flavonoid Content

The procedure followed the method described by Fogarasi et al. [28] with some modifications. In brief, 100 µL of the extract was diluted to a final volume of 5 mL in a 16 mL glass bottle sealed with a rubber stopper, using 900 µL of methanol and 4 mL of distilled water. Subsequently, 300 µL of 5% (*w*/*v*) sodium nitrite solution was added and mixed using a vortex. Following 5 min, 300 µL of 10% (*w*/*v*) aluminium chloride solution was added, followed by the addition of 2 mL of 1 N sodium hydroxide solution and 2.4 mL of distilled water over the next 6 min. The mixture was incubated at room temperature for 5 min. Its absorbance was measured at 410 nm relative to a blank using a UV-Vis spectrophotometer. The blank consisted of 70% (*v*/*v*) methanol and was subjected to the same procedures as the test sample. Quercetin at levels from 0.05 to 0.5 mg/mL was used to construct the calibration curve. Results were reported in mg quercetin equivalents (QUE)/g sample.

2.3.3. Determination of Trolox Equivalent Antioxidant Capacity by ABTS Assay

The ABTS assay was conducted as detailed by Socaciu et al. [29]. A stock solution was prepared by combining equal volumes of 7.4 mM ABTS and 2.6 mM potassium persulfate, and the mixture was incubated at room temperature in the dark for 12 h. Then, 3.6 mL of the stock solution was diluted with 120 mL of methanol to obtain a working solution with an absorbance of 1.1 ± 0.02 units at 734 nm.

An aliquot of 150 µL of the extract was introduced into a 16 mL glass bottle, which was sealed with a rubber stopper. Then, 2850 µL of the ABTS working solution was added, and the mixture was vortexed. The mixture was incubated in the dark at room temperature for 2 h. Its absorbance was measured at 734 nm relative to methanol using a UV-Vis spectrophotometer. The blank was prepared using 70% (*v*/*v*) methanol and subjected to the same procedures as the test sample. The extract absorbance value was subtracted from the blank absorbance. Trolox at levels from 25 to 600 µmol/L was used to construct the calibration curve. Results were reported as µmol Trolox equivalent (TE)/g sample.

2.3.4. Determination of Trolox Equivalent Antioxidant Capacity by DPPH Assay

The DPPH assay was conducted as detailed by Thaipong et al. [30]. Initially, 24 mg of DPPH was dissolved in 100 mL of methanol. Subsequently, 24 mL of this solution was combined with 90 mL of methanol to achieve an absorbance of 1.1 ± 0.02 units at 515 nm, yielding the working solution.

An aliquot of 150 µL of the extract was introduced into a 16 mL glass bottle, which was sealed with a rubber stopper. Then, 2850 µL of the DPPH working solution was added, and the mixture was vortexed. The mixture was then incubated in the dark at room temperature for 1 h. Its absorbance was measured at 515 nm relative to methanol using a UV-VIS spectrophotometer. The blank was prepared using 70% (*v*/*v*) methanol and subjected to the same procedures as the test sample. The extract absorbance value was subtracted from the blank absorbance value. Trolox at levels from 25 to 800 µmol/L was used to prepare the calibration curve. Results were reported in µmol Trolox equivalent (TE)/g sample.

2.3.5. Determination of Individual Polyphenol Content by HPLC-DAD-ESI/MS

The analysis was performed using the HPLC-DAD-ESI/MS method reported by Fogarasi et al. [28] and Socaciu et al. [31], with some modifications. Individual polyphenols were separated, identified, and quantified using an Agilent 1200 HPLC system (Palo Alto, CA, USA) equipped with a photodiode array detector (PDA), a single-quadrupole mass spectrometer (MS), and an electrospray ionisation (ESI) source. The system was also configured with a quaternary pump, autosampler, Kinetex XB-C18 column

(150 mm L × 4.6 mm ID × 5 µm particle size; Phenomenex, Torrance, CA, USA), and the Rev B.02.01 SR2 ChemStation software (Agilent, Palo Alto, CA, USA).

A 20 µL aliquot of the extract was loaded onto the HPLC column. The elution process utilised two mobile phases: solution A, 0.1% acetic acid in ultrapure water, and solution B, 0.1% acetic acid in acetonitrile. The multi-step gradient elution model was programmed as follows: 5% B (0–2 min), 5–40% B (2–18 min), 40–90% B (18–20 min), 90% B (20–24 min), 90–5% B (24–25 min), and 5% B (25–30 min). The column oven was set to 25 °C, while the flow rate was fixed at 0.5 mL/min. The PDA was configured to scan from 200 to 600 nm. Data acquisition lasted 30 min, and chromatograms were recorded at 280 and 340 nm.

The MS was operated in full-scan mode (m/z 120−1200) with the ESI source set to positive-ion mode for mass-spectral acquisition. The drying gas employed was nitrogen. Additional ESI source settings consisted of 350 °C for the drying gas, 7 L/min for the gas flow rate, 35 psi for the nebuliser pressure, 3000 V for the capillary voltage, and 100 eV for the fragmentor voltage. Tentative identification of polyphenols was achieved by comparing retention times, UV-Vis and mass spectra with those of corresponding standards analysed under identical experimental conditions and with previously reported data [32–35].

Methanol was the solvent used to prepare standard solutions of catechin, rutin, cyanidin, chlorogenic acid, and gallic acid. Quantification was performed using five-point analytical curves: catechin (10–200 µg/mL; R^2 = 0.9985; LOD = 0.18 µg/mL; LOQ = 0.55 µg/mL) for flavanols, rutin (10–100 µg/mL; R^2 = 0.9981; LOD = 0.21 µg/mL; LOQ = 0.64 µg/mL) for flavonols, cyanidin (10–100 µg/mL; R^2 = 0.9951; LOD = 0.36 µg/mL; LOQ = 1.09 µg/mL) for anthocyanins, chlorogenic acid (10–50 µg/mL; R^2 = 0.9937; LOD = 0.41 µg/mL; LOQ = 1.24 µg/mL) for hydroxycinnamic acids, and gallic acid (5–100 µg/mL; R^2 = 0.9978; LOD = 0.35 µg/mL; LOQ = 1.06 µg/mL) for hydroxybenzoic acids. Results were reported as milligrams per gram.

2.4. Statistical Analysis

Version 19.1.1 of Minitab statistical software (LEAD Technologies, Charlotte, NC, USA) was employed to analyse data. A one-way analysis of variance (ANOVA) followed by Tukey's post hoc test was conducted to evaluate the effects of each treatment on the measured parameters in rosehip samples at the 95% confidence level ($p < 0.05$). Pearson correlation analysis was also used to examine the relationships between the amounts of bioactive compounds (total phenolic and flavonoid contents) and antioxidant capacity measured by ABTS and DPPH assays. Correlation coefficients (r) and p-values were calculated to assess the strength and significance of these relationships.

3. Results and Discussion

3.1. Subsection Proximate Composition, pH, and Energy Content of Rosehip Samples

Table 1 displays the chemical composition of rosehip fruits used as a raw material for purée preparation via two methods: traditional (boiling) and modern (cold screw pressing). Proximate analysis revealed high moisture and carbohydrate contents (56.58% and 38.96%, respectively), along with low protein and ash contents (2.68% and 1.78%, respectively). Only trace amounts of fat were detected. The sample exhibited an energy content of 167 kcal/100 g and a pH of 3.90. These results align with those reported by Vasilj et al. [36], who analysed *Rosa canina* from various Bosnian locations and found moisture contents of 44.89–47.72% and ash contents of 2.15–2.41%. In comparison, Ercisli [37] observed higher moisture (62.00%) and fat (1.78%) contents, as well as a slightly higher pH (4.07), in *Rosa canina* fruits from Turkey.

Table 1. Proximate composition, pH, and energy content of rosehip fruit, purée, juice, waste, and powder.

Type of Sample	Sample	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Total Carbohydrate (%)	pH	Energy Content (kcal/100 g)
Fruit	R	56.58 ± 1.860 ^{d}	2.68 ± 0.021 ^{cde}	tr.	1.78 ± 0.085 ^{b}	38.96 ± 1.761 ^{e}	3.90 ± 0.008 ^{h}	167 ± 7.064 ^{e}
Purée & Juice	Pr	70.53 ± 0.212 ^{bB}	1.71 ± 0.057 ^{fA}	tr.	1.35 ± 0.007 ^{cdA}	26.37 ± 0.148 ^{gA}	4.11 ± 0.019 ^{gB}	113 ± 0.948 ^{gA}
	Jbwp	91.05 ± 0.0 ^{aA}	2.19 ± 0.290 ^{efA}	0.25 ± 0.035 ^{d}	0.34 ± 0.0 ^{fB}	6.18 ± 0.255 ^{hB}	4.38 ± 0.009 ^{eA}	36 ± 0.177 ^{hB}
Waste	RW	47.12 ± 0.905 ^{eB}	3.11 ± 0.035 ^{bcdA}	1.74 ± 0.057 ^{dB}	1.43 ± 0.085 ^{cdA}	46.61 ± 0.841 ^{dB}	4.24 ± 0.011 ^{fC}	215 ± 2.998 ^{dB}
	BW	61.26 ± 0.141 ^{cA}	2.42 ± 0.0 ^{defAB}	tr.	0.95 ± 0.078 ^{eB}	34.87 ± 0.283 ^{fC}	4.45 ± 0.015 ^{dB}	151 ± 0.219 ^{fC}
	BWp	30.41 ± 0.191 ^{fC}	2.90 ± 0.212 ^{cdeB}	4.59 ± 0.113 ^{bcA}	1.21 ± 0.106 ^{dAB}	61.38 ± 0.184 ^{cA}	5.04 ± 0.016 ^{aA}	297 ± 1.754 ^{cA}
Powder	RWd	6.80 ± 0.148 ^{gA}	3.29 ± 0.219 ^{abcAB}	4.43 ± 0.057 ^{bcB}	2.47 ± 0.042 ^{aA}	83.02 ± 0.170 ^{bB}	4.07 ± 0.008 ^{gD}	385 ± 0.707 ^{bC}
	RWl	6.47 ± 0.049 ^{gA}	3.40 ± 0.007 ^{abcAB}	4.28 ± 0.453 ^{cB}	2.42 ± 0.007 ^{aA}	83.45 ± 0.403 ^{bB}	3.80 ± 0.007 ^{iE}	386 ± 2.489 ^{bC}
	BWd	4.00 ± 0.085 ^{hB}	2.75 ± 0.0 ^{cdeB}	7.00 ± 1.181 ^{aA}	1.54 ± 0.057 ^{bcBC}	85.16 ± 1.223 ^{abAB}	4.75 ± 0.028 ^{cB}	407 ± 0.361 ^{aB}
	BWl	2.76 ± 0.014 ^{hD}	3.66 ± 0.255 ^{abA}	6.76 ± 0.049 ^{aA}	1.57 ± 0.071 ^{bcB}	85.26 ± 0.389 ^{abAB}	4.19 ± 0.014 ^{fC}	416 ± 0.092 ^{aAB}
	BWpd	3.56 ± 0.099 ^{hC}	3.95 ± 0.318 ^{aA}	5.62 ± 0.106 ^{abcAB}	1.33 ± 0.042 ^{cdD}	85.11 ± 0.170 ^{abAB}	4.95 ± 0.010 ^{bA}	415 ± 5.735 ^{aAB}
	BWpl	1.63 ± 0.120 ^{hE}	3.98 ± 0.276 ^{aA}	6.02 ± 0.042 ^{abAB}	1.38 ± 0.049 ^{cdCD}	87.01 ± 0.304 ^{aA}	4.72 ± 0.007 ^{cB}	418 ± 0.495 ^{aA}

R, rosehip fruits; Pr, purée; Jbwp, juice from cold screw pressing of boiled processing waste; RW, raw processing waste; BW, boiled processing waste; BWp, boiled processing waste subjected to cold screw pressing; RWd, powder from raw processing waste subjected to hot-air drying; RWl, powder from raw processing waste subjected to lyophilisation; BWd, powder from boiled processing waste subjected to hot-air drying; BWl, powder from boiled processing waste subjected to lyophilisation; BWpd, powder from boiled processing waste subjected to hot-air drying after cold screw pressing; BWpl, powder from boiled processing waste subjected to lyophilisation after cold screw pressing; tr., traces. Data are presented as mean ± standard deviation of three independent determinations. Significant differences among all samples ($p < 0.05$, Tukey's test) are indicated by lowercase letters in the column, whereas between samples within the same group are indicated by uppercase letters.

The traditional processing of rosehip fruits into purée produced a solid material, referred to as "boiled processing waste" (BW), with a moisture content of 61.26%, significantly higher than the 47.12% in the "raw processing waste" (RW) from their modern processing. This elevated moisture content in the BW is likely due to water gain by the fruits through osmosis during their boiling [38]. Moreover, BW exhibited a significantly lower energy content than RW, attributed to its higher moisture content, lower fat, ash, and carbohydrate contents, and comparable protein content (as shown in Table 1). When BW was subjected to cold screw pressing, its moisture content decreased substantially due to water loss, reaching 30.41% in the pressed boiled processing waste (BWp). This reduction in moisture content led to a significant increase in fat and carbohydrate contents, resulting in a higher energy content for BWp relative to BW. The juice fraction (Jbwp) obtained from cold screw pressing of BW recorded a moisture content of 91.05%.

Proximate analysis of powders obtained by hot-air drying and lyophilisation of the two waste types indicated that the moisture content of powders derived from RW was significantly higher (6.47% in RWl and 6.80% in RWd) compared to those from BW (2.76% in BWl and 4.00% in BWd), even though BW initially contained more water than RW (Table 1). This discrepancy may be explained by the greater amount of free water in BW, which was more readily lost during dehydration [39], whether by hot-air drying or lyophilisation. The excess free water in BW likely resulted from water absorption during boiling and from heat-induced breakdown of cellular structures that released additional intracellular water [40]. Compared to the powders analysed in the present study, Vartolomei and Turtoi [24] found that rosehip powder produced by air drying in the dark exhibited higher moisture (13.40%) and protein (4.89%) contents, but lower fat (0.76%) and ash (6.50%) contents, as well as a carbohydrate content of 73.66%.

Lyophilisation was found to be more effective than hot-air drying, particularly for preparing BW powders. The moisture content in BWl and BWpl (1.63%) was significantly lower than in BWd and BWpd (3.56%), respectively. However, there was no significant difference in moisture content between RWl and RWd. Cold screw pressing BW before dehydration significantly reduced the moisture content only between BWl and BWpl, but

not between BWd and BWpd. This finding further underscores the superior efficiency of lyophilisation in dehydrating this type of waste.

Powders made from BW exhibited significantly higher energy contents (407 kcal/100 g for BWd and 416 kcal/100 g for BWl) compared to those made from RW (385 kcal/100 g for RWd and 386 kcal/100 g for RWl). This difference is attributed to the lower moisture and ash contents, as well as the higher fat content, in BW powders, while protein and carbohydrate contents did not exhibit significant variation between the two powder types. Additionally, cold screw pressing BW before dehydration did not significantly affect the energy content, with BWpd at 415 kcal/100 g compared to BWd, and BWpl at 418 kcal/100 g compared to BWp. Other nutritional components in powders ranged from 2.75% to 3.98% for protein, 4.28% to 7.00% for fat, 1.33% to 2.47% for ash, and 83.02% to 87.01% for carbohydrates, depending on the treatment applied.

As for the powders' pH values, they were significantly lower in the lyophilised samples (3.80 for RWl, 4.19 for BWl, and 4.72 for BWpl) than in the hot-air-dried samples (4.07 for RWd, 4.75 for BWd, and 4.95 for BWpd). Powders prepared from RW were slightly more acidic than those prepared from BW. Furthermore, cold screw pressing of BW before dehydration resulted in a reduction in the powder's acidity.

3.2. TPC, TFC, TEAC-ABTS, and TEAC-DPPH of Rosehip Samples

The TPC in rosehip fruits was measured at 10.74 mg GAE/g, while the TFC was found to be 8.01 mg QUE/g (Table 2). For comparison, Dolek et al. [3] reported TPC values of 5.38–8.17 mg GAE/g in *Rosa canina* fruits grown in Turkey from 2011 to 2012, alongside TEAC-ABTS antioxidant activities of 114.05–150.79 µmol TE/g. Although their TPCs were comparable to those in the current study, their markedly higher antioxidant activities suggest that additional compounds, most likely vitamin C, also contributed to the overall activity. In the study by Soare et al. [41], TFC in rosehips harvested from the indigenous flora of southern Romania varied from 2.06 to 6.72 mg QE/g depending on the *Rosa canina* genotype, with TEAC-DPPH values of 0.99–3.63 µmol TE/g.

Table 2. TPC, TFC, TEAC-ABTS, and TEAC-DPPH of rosehip fruit, purée, juice, waste, and powder.

Type of Sample	Sample	TPC (mg GAE/g)	TFC (mg QUE/g)	TEAC-ABTS (µmol TE/g)	TEAC-DPPH (µmol TE/g)
Fruit	R	10.74 ± 0.106^{d}	8.01 ± 0.509^{b}	27.62 ± 1.161^{d}	77.38 ± 1.959^{d}
Purée & Juice	Pr	14.15 ± 0.021^{cA}	8.61 ± 0.318^{bA}	50.97 ± 3.619^{cA}	110.55 ± 1.138^{cA}
	Jbwp	8.16 ± 0.255^{eB}	3.81 ± 0.290^{cB}	21.06 ± 1.287^{eB}	62.23 ± 1.803^{eB}
Waste	RW	9.16 ± 0.658^{eA}	4.32 ± 0.820^{c}	28.25 ± 2.655^{dA}	58.30 ± 5.678^{eA}
	BW	4.53 ± 0.035^{gB}	n.d.	20.52 ± 0.517^{eB}	19.84 ± 0.021^{gB}
	BWp	2.71 ± 0.057^{hC}	n.d.	10.26 ± 0.443^{fC}	15.23 ± 0.502^{gB}
Powder	RWd	20.01 ± 0.354^{bB}	19.53 ± 0.028^{aA}	58.01 ± 1.888^{bB}	150.01 ± 4.561^{bB}
	RWl	27.16 ± 0.226^{aA}	20.35 ± 0.940^{aA}	89.13 ± 0.204^{aA}	163.99 ± 1.471^{aA}
	BWd	6.86 ± 0.346^{fC}	4.08 ± 0.276^{cB}	23.33 ± 0.311^{deC}	30.72 ± 0.891^{fC}
	BWl	6.49 ± 0.148^{fC}	3.47 ± 0.106^{cB}	25.70 ± 1.583^{deC}	31.87 ± 0.445^{fC}
	BWpd	3.32 ± 0.113^{hD}	4.18 ± 0.042^{cB}	9.22 ± 0.490^{fD}	14.49 ± 0.750^{gD}
	BWpl	2.95 ± 0.078^{hD}	1.25 ± 0.205^{dC}	8.94 ± 0.598^{fD}	15.16 ± 0.389^{gD}

R, rosehip fruits; Pr, purée; Jbwp, juice from cold screw pressing of boiled processing waste; RW, raw processing waste; BW, boiled processing waste; BWp, boiled processing waste subjected to cold screw pressing; RWd, powder from raw processing waste subjected to hot-air drying; RWl, powder from raw processing waste subjected to lyophilisation; BWd, powder from boiled processing waste subjected to hot-air drying; BWl, powder from boiled processing waste subjected to lyophilisation; BWpd, powder from boiled processing waste subjected to hot-air drying after cold screw pressing; BWpl, powder from boiled processing waste subjected to lyophilisation after cold screw pressing; TPC, total phenolic content; TFC, total flavonoid content; TEAC-ABTS, Trolox equivalent antioxidant capacity measured using the ABTS assay; TEAC-DPPH, Trolox equivalent antioxidant capacity measured using the DPPH assay; n.d., not detected. Data are presented as mean ± standard deviation of three independent determinations. Significant differences among all samples ($p < 0.05$, Tukey's test) are indicated by lowercase letters in the column, whereas between samples within the same group are indicated by uppercase letters.

The processing of rosehip fruits affected TPC, TFC, TEAC-DPPH, and TEAC-ABTS in waste, purée, and juice. When traditional boiling was applied, both the resulting waste (BW) and juice (Jbwp) showed significantly lower values for all four parameters than in the raw material. In BW, TPC decreased to 4.53 mg GAE/g, and TFC was completely reduced, indicating losses of phenolic and flavonoid compounds, likely due to leaching into boiling water [42] and partial degradation during heating. Antioxidant capacity in BW also declined, with TEAC-ABTS and TEAC-DPPH values of 20.52 μmol TE/g and 19.84 μmol TE/g, respectively. In Jbwp, TPC and TFC fell to 8.16 mg GAE/g and 3.81 mg QUE/g, while TEAC-ABTS and TEAC-DPPH dropped to 21.06 μmol TE/g and 62.23 μmol TE/g, respectively. Modern processing of rosehip fruits by cold screw pressing produced a waste (RW) and purée (Pr) with higher retention of these bioactive compounds compared to the traditional method. From rosehip fruits to RW, both TPC and TFC showed significant decreases. However, the antioxidant capacity of RW remained relatively high, likely due to the higher overall concentration of antioxidant compounds in the solid fraction resulting from cold screw pressing. In Pr, both TPC (14.15 mg GAE/g) and TFC (8.61 mg QUE/g) were better preserved than in RW, with the highest antioxidant capacity, as indicated by TEAC-ABTS and TEAC-DPPH values of 50.97 μmol TE/g and 110.55 μmol TE/g, respectively. Cold screw pressing of BW before dehydration further reduced the TPC and antioxidant capacity, with BWp showing values of 2.71 mg GAE/g for TPC, 10.26 μmol TE/g for TEAC-ABTS, and 15.23 μmol TE/g for TEAC-DPPH. Overall, the results indicate that cold screw pressing is a more effective method for recovering bioactive-compound-rich waste, with RW maintaining higher TPC (9.16 mg GAE/g), TFC (4.32 mg QUE/g), and TEAC values than BW, highlighting the importance of processing choice in optimising the nutritional and functional quality of rosehip by-products. TFC in samples of waste, purée, and juice was more affected by the processing of rosehip fruits than TPC, regardless of the method used. This increased susceptibility of flavonoids may be attributed to their chemical structure, which makes them more prone to oxidation [43]. Overall, these data indicate that processing rosehip fruits through cold screw pressing is a more effective method for recovering waste rich in bioactive compounds. RW contained a TPC of 9.16 mg GAE/g and a TFC of 4.32 mg QUE/g, both above the values found in BW. Consequently, RW exhibited greater antioxidant capacity, with 28.25 μmol TE/g for TEAC-ABTS and 58.30 μmol TE/g for TEAC-DPPH. These findings emphasise that the choice of processing method is critical for maintaining the nutritional and functional quality of rosehip waste.

Dehydration of RW and BW by both hot-air drying and lyophilisation resulted in significant increases in TPC and TFC values in the resulting powders (6.49–27.16 mg GAE/g and 3.47–20.35 mg QUE/g, respectively), due to concentration resulting from water removal. This concentration also resulted in higher TEAC-ABTS and TEAC-DPPH values in these powders (23.33–89.13 μmol TE/g and 30.72–163.99 μmol TE/g, respectively). In the case of BWp, dehydration resulted in a significant increase in TFC (1.25–4.18 mg QUE/g) only, regardless of the dehydration method. In contrast, TPC, TEAC-ABTS, and TEAC-DPPH values remained relatively stable, ranging from 2.95 to 3.18 mg GAE/g, 8.94 to 9.22 μmol TE/g, and 14.49 to 15.16 μmol TE/g, respectively.

Lyophilisation proved more effective than hot-air drying for solely dehydrating RW, resulting in the highest TPC, TFC, TEAC-ABTS, and TEAC-DPPH values in RWl. However, the marginally lower values observed in RWd (20.01 mg GAE/g for TPC, 19.53 mg QUE/g for TFC, 58.01 μmol TE/g for TEAC-ABTS, and 150.01 μmol TE/g for TEAC-DPPH) do not justify the considerably higher costs associated with lyophilisation. In summary, to achieve the highest concentration of phenolic and flavonoid compounds in rosehip powder, it should be prepared from raw processing waste. This research investigates, for the first time, TPC, TFC, TEAC-ABTS, and TEAC-DPPH in rosehip waste powder. Igual et al. [44],

instead, studied a powder obtained from rosehip purée. The lyophilised sample exhibited a comparable TPC value of 24.82 mg GAE/g but a considerably lower TEAC-DPPH value of 17.93 µmol TE/g than our lyophilised powder.

Pearson correlation analyses were conducted to assess the relationships between bioactive compound contents and antioxidant capacity. Very strong positive correlations were found between TPC and TEAC-ABTS ($r = 0.993$, $p < 0.001$), as well as between TPC and TEAC-DPPH ($r = 0.985$, $p < 0.001$). Similarly, TFC exhibited very strong positive correlations with both TEAC-ABTS ($r = 0.937$, $p < 0.001$) and TEAC-DPPH ($r = 0.991$, $p < 0.001$). These findings indicate that phenolic and flavonoid compounds are contributors to the antioxidant capacity of rosehip waste powders and reinforce the mechanistic relationship between bioactive compound retention and antioxidant potential discussed in this study. However, it should be noted that ABTS and DPPH assays estimate the radical-scavenging capacity of the samples under in vitro conditions and therefore may not fully reflect biological antioxidant activity in vivo.

Furthermore, extending the Pearson correlation analysis to carotenoid fractions, specifically polar carotenoids (PC) and non-polar carotenoids (NP-C), quantified in the six rosehip powders in our previous study [15], revealed significant positive associations with antioxidant capacity. TEAC-ABTS correlated positively with both PC ($r = 0.828$, $p < 0.005$) and NP-C ($r = 0.835$, $p < 0.005$). TEAC-DPPH showed even stronger correlations with PC ($r = 0.924$, $p < 0.001$) and NP-C ($r = 0.924$, $p < 0.001$). Together, these results demonstrate that maintaining elevated levels of bioactive compounds—including phenolics, flavonoids, and carotenoids—is essential to preserve the antioxidant capacity of rosehip waste powder.

3.3. Individual Polyphenol Content in Rosehip Samples

Table 3 shows the chromatographic profile of polyphenolic compounds in all rosehip samples, including the content of each identified compound. Eighteen individual polyphenolic compounds were found in rosehip fruits, with a total content of 17.03 mg/g. Flavonoids were the dominant class, making up 15.03 mg/g, while phenolic acids accounted for 2.00 mg/g. Within the flavonoid group, flavanols were the largest subclass (14.73 mg/g), followed by flavonols (0.25 mg/g) and anthocyanins (0.06 mg/g). The phenolic acid class mainly consisted of hydroxybenzoic acids (1.98 mg/g) with a small amount of hydroxycinnamic acids (0.02 mg/g). The most abundant individual compounds included catechin (4.66 mg/g), procyanidin dimer B2 (3.68 mg/g), procyanidin dimer B3 (2.71 mg/g), and procyanidin trimer C2 (2.29 mg/g). Similarly, Goztepe et al. [45] reported catechin (3.47 mg/g) as the primary polyphenolic compound in rosehip fruits. The other quantified compounds were rutin (1.37 mg/g), kaempferol (1.01 mg/g), gallic acid (0.87 mg/g), ellagic acid (0.65 mg/g), syringic acid (0.50 mg/g), vanillic acid (0.42 mg/g), ferulic acid (0.25 mg/g), protocatechuic acid (0.24 mg/g), quercetin (0.17 mg/g), and *p*-coumaric acid (0.14 mg/g).

As seen with TPC and TFC, the total polyphenolic content was lower in RW (12.27 mg/g), BW (6.57 mg/g), and BWp (4.06 mg/g) compared to rosehip fruits, indicating that a substantial amount of soluble phenolics was introduced into the purée (30.82 mg/g) or juice (10.79 mg/g) fraction during cold screw pressing. The lower levels of flavonoids and phenolic acids in BW (5.69 mg/g and 0.88 mg/g, respectively) compared to RW (9.93 mg/g and 2.34 mg/g, respectively) may be attributed to thermal degradation during traditional boiling processing of rosehip fruits [46]. Furthermore, cold screw pressing of BW before dehydration further decreased the flavonoid and phenolic acid contents, reaching 3.34 mg/g and 0.72 mg/g, respectively, in BWd.

Table 3. Content of individual polyphenols in rosehip fruit, purée, juice, waste, and powder.

Crt. No.	Polyphenol	Fruit	Purée & Juice		Waste			Powder					
		R	Pr	Jbwp	RW	BW	BWp	RWd	RWl	BWd	BWl	BWpd	BWpl
		(mg/g)											
1	2-Hydroxybenzoic acid	1.13 ± 0.067 ^{cd}	1.53 ± 0.007 $_{bA}$	0.90 ± 0.052 ^{dB}	1.55 ± 0.063 $_{bA}$	0.45 ± 0.015 ^{eB}	0.16 ± 0.006 ^{eC}	1.45 ± 0.001 $_{bcB}$	4.23 ± 0.272 ^{aA}	1.06 ± 0.032 ^{dB}	1.17 ± 0.027 $_{cdB}$	0.29 ± 0.0 ^{eC}	0.19 ± 0.020 ^{eC}
2	Procyanidin dimer B1	1.02 ± 0.064 ^{d}	1.57 ± 0.250 ^{cA}	0.63 ± 0.035 $_{efB}$	0.74 ± 0.007 $_{deA}$	0.40 ± 0.007 $_{fgB}$	0.26 ± 0.006 ^{gC}	2.52 ± 0.112 ^{bB}	2.92 ± 0.021 ^{aA}	0.64 ± 0.047 ^{efC}	0.52 ± 0.038 $_{efgCD}$	0.32 ± 0.023 $_{fgDE}$	0.28 ± 0.033 ^{gE}
3	Protocatechuic acid	0.57 ± 0.048 ^{cd}	1.43 ± 0.307 $_{bA}$	0.51 ± 0.047 $_{cdA}$	0.67 ± 0.072 ^{cA}	0.31 ± 0.006 $_{cdB}$	0.17 ± 0.006 ^{dB}	2.16 ± 0.145 ^{aA}	2.11 ± 0.007 ^{aA}	0.57 ± 0.064 $_{cdB}$	0.35 ± 0.036 $_{cdBC}$	0.22 ± 0.019 ^{dC}	0.21 ± 0.018 ^{dC}
4	Procyanidin dimer B3	2.71 ± 0.007 ^{c}	6.00 ± 0.128 $_{bA}$	1.96 ± 0.004 $_{deB}$	2.36 ± 0.147 $_{cdA}$	1.26 ± 0.011 $_{efB}$	0.42 ± 0.042 ^{gC}	7.36 ± 0.508 ^{aA}	7.68 ± 0.042 ^{aA}	1.96 ± 0.010 $_{deB}$	1.49 ± 0.263 $_{eBC}$	0.61 ± 0.053 $_{fgCD}$	0.54 ± 0.055 ^{gD}
5	Cyanidin 3-*O*-glucoside	0.06 ± 0.002 ^{a}	0.04 ± 0.001 ^{bc}	n.d.	0.04 ± 0.002 ^{b}	n.d.	n.d.	0.03 ± 0.001 ^{cB}	0.05 ± 0.001 ^{bA}	n.d.	n.d.	n.d.	n.d.
6	Procyanidin dimer B2	3.68 ± 0.108 ^{c}	6.56 ± 0.491 $_{bA}$	2.53 ± 0.024 $_{deB}$	2.74 ± 0.169 $_{dA}$	1.42 ± 0.006 $_{fgB}$	0.63 ± 0.010 $_{hC}$	8.51 ± 0.302 ^{aA}	8.83 ± 0.144 ^{aA}	2.10 ± 0.029 $_{defB}$	1.80 ± 0.146 ^{efB}	0.81 ± 0.043 $_{ghC}$	0.73 ± 0.037 $_{ghC}$
7	Procyanidin trimer C2	2.29 ± 0.103 ^{c}	4.22 ± 0.252 $_{bA}$	1.49 ± 0.034 ^{dB}	1.43 ± 0.123 $_{dA}$	0.86 ± 0.042 $_{efB}$	0.42 ± 0.008 ^{gC}	5.38 ± 0.027 ^{aB}	5.73 ± 0.090 ^{aA}	1.32 ± 0.093 ^{dC}	1.12 ± 0.122 $_{deC}$	0.55 ± 0.030 $_{fgD}$	0.52 ± 0.064 $_{fgD}$
8	Catechin	4.66 ± 0.260 ^{b}	8.23 ± 0.518 ^{aA}	2.35 ± 0.012 ^{cB}	2.32 ± 0.117 ^{cA}	1.47 ± 0.040 $_{cdeB}$	0.97 ± 0.005 ^{eC}	8.21 ± 0.231 ^{aA}	7.90 ± 0.400 ^{aA}	2.36 ± 0.001 ^{cB}	2.22 ± 0.196 $_{cdBC}$	1.38 ± 0.081 $_{deCD}$	1.15 ± 0.127 ^{eD}
9	Procyanidin trimer C1	0.36 ± 0.023 ^{de}	0.71 ± 0.009 ^{cA}	0.22 ± 0.005 $_{efB}$	0.10 ± 0.006 ^{fC}	0.16 ± 0.003 $_{efB}$	0.97 ± 0.005 $_{bA}$	1.05 ± 0.134 $_{bA}$	1.30 ± 0.031 ^{aA}	0.52 ± 0.013 $_{cdB}$	0.44 ± 0.078 ^{dB}	0.53 ± 0.088 $_{cdB}$	0.37 ± 0.052 $_{deB}$
10	Ellagic acid glucoside	0.10 ± 0.003 ^{c}	0.14 ± 0017 ^{cA}	0.03 ± 0.001 ^{dB}	0.01 ± 0.001 ^{dB}	0.02 ± 0.0 ^{dB}	0.27 ± 0.011 $_{abA}$	0.32 ± 0.031 ^{aA}	0.22 ± 0.013 ^{bB}	0.12 ± 0.011 ^{cC}	0.09 ± 0.019 ^{cC}	0.13 ± 0.028 ^{cC}	0.09 ± 0.008 ^{cC}
11	Vanillin	0.11 ± 0.006 ^{d}	0.11 ± 0.006 $_{dA}$	0.05 ± 0.001 ^{eB}	0.03 ± 0.001 ^{eC}	0.06 ± 0.001 $_{deA}$	0.04 ± 0.003 ^{eB}	0.36 ± 0.022 ^{aA}	0.35 ± 0.013 ^{aA}	0.28 ± 0.005 ^{bB}	0.19 ± 0.023 ^{cB}	0.27 ± 0.033 ^{bB}	0.24 ± 0.028 ^{bcB}
12	Quercetin 3-*O*-glucoside	0.07 ± 0.008 ^{b}	0.06 ± 0.001 $_{bA}$	0.02 ± 0.001 ^{dB}	0.05 ± 0.001 ^{cB}	0.03 ± 0.002 $_{dC}$	0.14 ± 0.002 ^{aA}	0.14 ± 0.002 ^{aA}	0.14 ± 0.001 ^{aA}	0.05 ± 0.001 ^{cB}	0.04 ± 0.002 ^{cB}	0.04 ± 0.0 ^{cB}	0.04 ± 0.001 ^{cB}
13	Ellagic acid	0.05 ± 0.004 ^{c}	0.03 ± 0.001 ^{d}	n.d.	0.03 ± 0.002 $_{dA}$	0.01 ± 0.002 ^{eB}	0.04 ± 0.001 $_{dA}$	0.13 ± 0.001 $_{bA}$	0.14 ± 0.004 ^{aA}	0.06 ± 0.005 ^{cB}	0.05 ± 0.004 ^{cB}	0.05 ± 0.001 ^{cB}	0.05 ± 0.001 ^{cB}
14	Quercetin 3-*O*-glucuronide	0.07 ± 0.003 ^{b}	0.06 ± 0.001 ^{cA}	0.02 ± 0.001 ^{fB}	0.03 ± 0.003 ^{eB}	0.02 ± 0.001 ^{fC}	0.04 ± 0.001 $_{dA}$	0.10 ± 0.0 ^{aA}	0.09 ± 0.001 ^{aA}	0.06 ± 0.002 ^{cB}	0.03 ± 0.001 $_{deC}$	0.03 ± 0.0 ^{eC}	0.03 ± 0.001 $_{deC}$
15	Kaempferol 3-*O*-glucoside	0.09 ± 0.009 ^{b}	0.06 ± 0.001 $_{dA}$	0.03 ± 0.001 ^{eB}	0.06 ± 0.004 $_{dA}$	0.03 ± 0.003 ^{eB}	0.06 ± 0.003 $_{dA}$	0.17 ± 0.0 ^{aA}	0.17 ± 0.004 ^{aA}	0.07 ± 0.002 $_{cdBC}$	0.07 ± 0.004 $_{cdC}$	0.08 ± 0.001 $_{bcC}$	0.07 ± 0.003 $_{cdBC}$
16	5-Sinapoylquinic acid	0.02 ± 0.0 ^{e}	0.02 ± 0.0 ^{eA}	0.02 ± 0.0 ^{eA}	0.02 ± 0.001 ^{eB}	0.02 ± 0.002 ^{eB}	0.06 ± 0.004 ^{cA}	0.04 ± 0.004 $_{dC}$	0.05 ± 0.0 ^{dC}	0.06 ± 0.004 ^{cB}	0.06 ± 0.004 ^{cB}	0.09 ± 0.001 ^{aA}	0.08 ± 0.003 ^{bA}
17	Syringic acid	0.02 ± 0.004 ^{f}	0.03 ± 0.001 ^{fA}	0.02 ± 0.001 ^{fA}	0.03 ± 0.001 ^{fB}	0.03 ± 0.0 ^{fB}	0.07 ± 0.005 ^{cA}	0.06 ± 0.001 $_{deDE}$	0.05 ± 0.0 ^{eE}	0.08 ± 0.003 ^{cC}	0.06 ± 0.004 ^{dD}	0.09 ± 0.0 ^{bB}	0.10 ± 0.003 ^{aA}
18	Tiliroside	0.02 ± 0.001 ^{fg}	0.03 ± 0.001 $_{fgA}$	0.02 ± 0.0 ^{gB}	0.05 ± 0.004 ^{fB}	0.04 ± 0.002 $_{fgC}$	0.25 ± 0.0 ^{bA}	0.17 ± 0.023 $_{dBC}$	0.12 ± 0.004 ^{eC}	0.21 ± 0.006 ^{cB}	0.14 ± 0.005 $_{deC}$	0.31 ± 0.005 ^{aA}	0.31 ± 0.014 ^{aA}
Total content		17.03	30.82	10.79	12.27	6.57	4.06	38.14	42.09	11.50	9.83	5.80	5.00

R, rosehip fruits; Pr, purée; Jbwp, juice from cold screw pressing of boiled processing waste; RW, raw processing waste; BW, boiled processing waste; BWp, boiled processing waste subjected to cold screw pressing; RWd, powder from raw processing waste subjected to hot-air drying; RWl, powder from raw processing waste subjected to lyophilisation; BWd, powder from boiled processing waste subjected to hot-air drying; BWl, powder from boiled processing waste subjected to lyophilisation; BWpd, powder from boiled processing waste subjected to hot-air drying after cold screw pressing; BWpl, powder from boiled processing waste subjected to lyophilisation after cold screw pressing; n.d., not detected. Data are presented as mean ± standard deviation of three independent determinations. Significant differences among all samples ($p < 0.05$, Tukey's test) are indicated by lowercase letters in the row, whereas between samples within the same group are indicated by uppercase letters.

Dehydration of the three waste fractions using both hot-air drying and lyophilisation resulted in a concentration of TPC in the six resulting powders. The highest contents were observed in powders prepared from RW, with 38.14 mg/g in RWd and 42.09 mg/g in RWl. Powders derived from BW contained lower amounts of polyphenols, recorded as 11.50 mg/g in BWd, 9.83 mg/g in BWl, 5.80 mg/g in BWpd, and 5.00 mg/g in BWpl. Data on the polyphenol content in rosehip powder are scarce. Ghendov-Mosanu et al. [47] identified 16 polyphenolic compounds in powder prepared from rosehip fruits, with a total content of 0.78 mg/g, which is considerably lower than what was found in our powders. The most abundant compound in their sample was procyanidin dimer B1 (0.29 mg/g), followed by chlorogenic acid (0.10 mg/g).

4. Conclusions

This study evaluated how the rosehip fruit-processing method and the dehydration technique applied to processing waste influence the chemical composition and antioxidant capacity of the resulting powder. The results showed that cold screw pressing retained higher levels of phenolic and flavonoid compounds and resulted in greater antioxidant capacity than traditional boiling. Based on these findings, raw processing waste from cold screw pressing is the most suitable starting material for producing rosehip waste powder under the experimental conditions investigated.

Among the dehydration techniques evaluated, lyophilisation was more effective in removing moisture, particularly from boiled processing waste. In terms of bioactive compound retention, it showed advantages over hot-air drying only for raw processing waste; however, the differences between the two methods were relatively small and should be considered alongside the substantially higher processing costs associated with lyophilisation.

Overall, this research provides a detailed characterisation of rosehip waste powder with respect to its chemical composition and antioxidant potential, supporting its potential use in the development of nutrient-dense, antioxidant-rich food formulations.

These findings may be relevant to the food and nutraceutical industries seeking to develop products enriched with natural antioxidants, as well as to small-scale processors aiming to increase the value of rosehip-processing waste. Future research will investigate the effects of rosehip waste powder on lipid composition and oxidative stability in food systems.

Author Contributions: Conceptualisation, C.A.S.; methodology, C.A.S.; software, C.A.S.; validation, C.A.S.; formal analysis, A.R.B. and F.R.; investigation, A.R.B. and C.A.S.; resources, A.R.B., C.A.S. and F.R.; data curation, A.R.B. and C.A.S.; writing—original draft preparation, A.R.B. and C.A.S.; writing—review and editing, C.A.S.; visualisation, A.R.B. and C.A.S.; supervision, C.A.S.; funding acquisition, A.R.B. and C.A.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: No new data were created or analysed in this study.

Acknowledgments: We are grateful for the administrative and financial support from the University of Agricultural Sciences and Veterinary Medicine of Cluj-Napoca, Romania.

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

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