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Effect of convective drying on phenolic acid, flavonoid and anthocyanin content, texture and microstructure of black rosehip fruit

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ABSTRACT

Black rosehip (*Rosa pimpinellifolia*) fruit is rich in nutrients that could be valorised and used as a functional food ingredient. Drying can be applied to increase the applications of this fruit. Drying can influence the composition of heat-sensitive phytochemicals and the matrix in terms of the texture and microstructure of the fruit. This study aimed to evaluate the effect of convective drying in terms of drying temperature (50–80 °C) and airflow (0.5–1.5 m/s) on phenolic acids, flavonoids, and anthocyanins content, texture, and microstructure of dried black rosehip fruit. Catechin and epicatechin, as the two main flavonoids, were in their highest concentration in fruits dried at 70 °C. The highest levels of cyanidin-3-glucoside, cyanine chloride, cyanidin-3-rutinoside, and pelargonidin-3-glucoside were determined at 70 °C and 1.5 m/s. The sample dried at 50 °C exhibited the highest concentrations of chlorogenic acid, fumaric acid, gallic acid, protocatechuic acid, quercetin, and quercetin-3-glucoside. The hardness, cohesiveness, and resilience were among the key texture parameters that were affected by drying temperature. The applied drying temperatures and air velocities induced substantial effects on the fruit microstructure. Considering these changes, it is important to assess the bioaccessibility and bioavailability of nutrients from dried black rosehip fruit in future research.

1. Introduction

It is very important to identify the customary uses of various plants and fruits and to form a state in which novel cultural or economic value is given to regional resources. While searching for different health and nutrition solutions, searching for new food sources has gained importance. Black rosehip (*R. pimpinellifolia* L. Syn. *Rosa spinosissima* L.) is important fruit to endogenous communities as it has a great place in folk medicine (Güler et al., 2021). Black rosehip belongs to the *Rosaceae* family and is the black variety of rosehip (Kasapoglu et al., 2023). Black rosehip has various uses in the food and pharmaceutical industries. It is processed into many products, including jams, marmalades, fruit juices, syrups, and tea, and is used in the production of fermented beverages and high-value cosmetic oils (Pashazadeh et al., 2020). In addition, fruits are added to many foods and beverages to improve the functional properties of foods.

Recently, rosehip has been the subject of numerous studies due to its bioactive properties. Rosehip berries exhibit a notable antioxidant potential, manifesting positive health effects attributed to an array of bioactive compounds encompassing phenolic acids, proteins and peptides, polysaccharides, essential fatty acids, organic acids, flavonoids, anthocyanins, carotenoids, minerals, and vitamins (Fascella et al., 2019; Zhou et al., 2023). Fruits and vegetables typically possess a substantial water content, resulting in a limited shelf life (Ma et al., 2017). Various

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techniques are employed to extend the storage duration of these perishables. Among the simplest approaches to enhance the shelf life of such produce is by reducing the water content to levels that inhibit microorganism growth (De Corato, 2020). Drying, one of the oldest preservation methods, stands as a cornerstone. Sun drying (open air) and convective drying using hot air are the prevailing techniques for drying fruits and vegetables (Devan et al., 2020). Concurrently, the realm of drying has advanced significantly with technological progress in recent years. Novel food drying methodologies, including vacuum, freeze, microwave, osmotic, spray, and fluidized bed drying, have undergone refinement (Wray and Ramaswamy, 2015). Despite the emergence of these innovative techniques, convective drying remains favored due to its simplicity and cost-effectiveness.

The perishability of black rosehip is akin to that of other fruits due to its high water content. Considering the intricate interplay of bioactive constituents, nutritional attributes, health implications, and industrial prospects associated with black rosehip fruit, the imperative for advanced research techniques to extend its shelf life becomes evident. Upon reviewing of existing literature, it becomes apparent that a scarcity of studies exists that delve into the phytochemical constituents and health-promoting attributes of black rosehip, protract its storage duration through convective drying methodologies and ascertain the impacts of drying on both quality and bioactive constituents. Consequently, the current study aimed to explore the effect of convective drying on phenolic acids, flavonoids, and anthocyanins in black rosehip. In addition, textural and microstructure analyses were conducted to understand how different convective drying conditions can change hardness, springiness, cohesiveness, gumminess, chewiness, and resilience.

2. Materials and methods

2.1. Chemicals and reagents

Fumaric acid (≥ 93%), gallic acid (≥ 99%), protocatechuic acid (≥ 98%), chlorogenic acid (≥ 95%), catechin (≥ 97%), epicatechin (≥ 98%), quercetin-3-glucoside (≥ 98%), quercetin (≥ 95%), quercetin-3-rutinoside (≥ 95%), cyanidin chloride (≥ 95%), cyanidin-3-glycoside (≥ 98%), cyanidin-3-rutinoside (≥ 90%), and pelargonidin-3-glycoside (≥ 95%) pure samples were purchased from Sigma-Aldrich (St. Louis, Missouri, United States). All solvents and reagents used were of analytical grade from Sigma-Aldrich (St. Louis, Missouri, United States). Ultrapure water (Milli-Q) was obtained using a Millipore system (Bedford, USA).

2.2. Samples

Freshly harvested black rosehip fruits were sourced from Horasan (40°02′23″N 42°10′16″E, 1600 m above sea level), Erzurum, Turkey in the Fall of 2019. Winters are very cold and snowy; summers are very hot and dry in this region. It is covered with snow 150 days a year. Temperature frequently drops below −30 °C in the winter months in this region. The amount of precipitation is 460 mm. The average temperature is 5.0 °C. An amount of 450 g of approximately 300 ± 1.85 black rosehip berries was sourced per experimental combination. The freshly gathered fruits were promptly cleaned, washed, and placed in storage at a temperature of 4–5 °C for 10 days. Before commencing the experimentation, the fruits were taken out from the refrigerator and left to stand for approximately 2 h to reach room temperature (20 °C).

2.3. Convective drying

A laboratory-scale cabinet dryer (EKSIS, Turkey) operating based on the principles of convection was used for drying. Similar drying setups have been effectively employed previously to study the drying kinetics of black rosehip fruits (Pashazadeh et al., 2021; Pashazadeh et al., 2020). The dimensions of the drying system utilized in the current investigation were 1.3 m in width, 1.5 m in depth, and 1.5 m in height. It was powered by a 5-watt voltage and featured an automated weighing system alongside trays. The system also boasted a user-friendly touchscreen interface for configuring parameters such as temperature, air velocity, relative humidity, time, and weighing intervals. This dryer encompassed components such as a centrifugal fan for air supply, an electric heater, an air filter, and a proportional temperature controller. Operating within a temperature range of 0–200 °C and air velocities ranging from 0.5 to 2 m/s, the dryer utilized 45 cm square and 11 cm tall perforated trays for sample placement. With its 10 trays, the convective dryer facilitated simultaneous drying. The extent of moisture loss was monitored based on the specified intervals for weighing.

The drying process for black rosehip fruits was conducted across four different temperatures: 50, 60, 70, and 80 °C, with three different air velocities in each condition: 0.5, 1.0, and 1.5 m/s. Prior to the experiment, the dryer was operated without any sample load for a duration of 10–20 min, enabling it to establish the necessary drying conditions. For every drying run, a total of 450 g of fruits were selected, uniformly divided into three separate portions, and loaded onto perforated trays in triplicates (150 g per sample, repeated three times). The process of moisture loss was continuously and automatically monitored at intervals of 15 min until a stable weight was achieved. Following this, the samples were retrieved from the dryer, cooled to room temperature, carefully packed into low-density polyethylene bags, and subsequently sealed.

2.4. Analysis of phenolic acids and flavonoids

The amount of fumaric acid (FA), gallic acid (GA), protocatechuic acid (PCHA), chlorogenic acid (CHA), catechin (C), epicatechin (EC), quercetin-3-glucoside (Q-3-G), quercetin (Q), and quercetin-3-rutinoside (Q-3-R) in all samples was determined using liquid chromatography coupled to a mass spectrometer detector (LC-MS/MS, Shimadzu LC-MS 8040) with electrospray ionization (ESI) and two pumps (LC-30 AD), an autosampler (SIL-30AC), a degassing unit (DGU-20A 3 R) and a column oven (CTO-10AS VP) (Zannou et al., 2021). The mass spectrometry system operated employing an ESI with a nebulizing gas flow rate of 3 L/min, DL temperature set at 250 °C, heat block temperature at 400 °C, and a drying gas flow rate of 15 L/min. Fresh and preserved samples were extracted with HPLC grade 80% methanol containing 0.1% hydrochloric acid. Both standards and samples underwent filtration through a 0.45-μm nylon filter, after which 15 μL was injected into a C18 reversed-phase column (Inertsil ODS-4, 3 μm, 4.6 × 50 mm, GL Sciences). The column temperature was maintained at 30 °C, and the mobile phase composition comprised water: formic acid in a ratio of 99.9:0.1 v/v (Mobile Phase A) and methanol: formic acid in a ratio of 99.9:0.1 v/v (Mobile Phase B) Solvent flow rate was set at 0.4 mL/min, following a gradient solution as follows in terms of mobile phase B: 0 min, 14% B; 34 min, 37% B; 36 min, 37% B; 51 min, 38% B; 53 min, 38% B; 67 min, 44% B; 69 min, 44% B; 69–90 min, 14% B; 95 min, 14% B. Phenolic compounds were identified based on their elution time and quantified using their respective peak areas. The quantification of these identified compounds relied on a mixture of external standards prepared by dissolving standards in methanol at concentrations ranging from 0 to 200 mg/L, with increments of 50 mg/L. Further information on the method can be found in the supplementary file.

2.5. Analysis of anthocyanins

The amount of cyanidin chloride (CC), cyanidin-3-glycoside (C-3-G), cyanidin-3-rutinoside (C-3-R), and pelargonidin-3-glycoside (P-3-G) in all samples was determined using a high-pressure liquid chromatography (HPLC) system (Agilent 1260; Agilent Technologies) coupled with a diode array detector (DAD) according to a previously established method with some modifications (Bosiljkov et al., 2017). Fresh and preserved samples were extracted with HPLC grade 80% methanol containing 0.1% hydrochloric acid. Anthocyanins were separated through the employment of an Inertsil ODS-4 column (3 μm, 4.6 ×50 mm; GL Sciences), with a flow rate maintained at 1 mL/min and measurements recorded at 520 nm. The mobile phases consisted of (A) a mixture of 6% acetic acid and 94% 2 mM sodium acetate (v/v) and (B) acetonitrile. The ensuing elution gradient, reliant on the concentration of solvent B, was as follows: 0–20 min, 14 −23%; 20–40 min, 23 −35%; 40–50 min, 40%; 50–60 min, 60%; 60–65 min, 95%; 65–80 min, 100%. The column temperature was sustained at 30 °C. Identification of individual anthocyanins was accomplished by aligning their retention times with those of corresponding standards, and quantification was conducted using a composite of external standards prepared at varying concentrations. Further information on the method can be found in the supplementary file.

2.6. Texture analysis

The evaluation of fruit texture involved employing one of the commonly utilized compression tests, namely Texture Profile Analysis (TPA), utilizing a texture analyzer (TA.XT.Plus, Stable Micro Systems, UK). The samples underwent two consecutive compression events, simulating the movement of a jaw. Compression was executed using TA-24 1/4 diameter acrylic cylinders, each measuring 35 mm in height, along with a compression plate featuring a 50 kg load cell. This procedure yielded a force-deformation curve through TPA, allowing the determination of attributes such as hardness, springiness, stickiness, gumminess, chewiness, and elasticity across varying drying temperatures. The quantification of these attributes was performed based on previously established methods (Guiné and Barroca, 2012).

2.7. Microstructure analysis

The analysis of the microstructure of both fresh and dried black rosehip samples involved the utilization of a scanning electron microscope (SEM, JEOL JSM-7001F), following a previously reported methodology (Hassan and Koca, 2022). Each fruit was meticulously prepared to achieve a uniform thickness of 1 mm, affixed onto the SEM stage, and subsequently subjected to examination under consistent parameters: high vacuum mode at 0.1 kPa. Multiple images of each fruit were captured from no fewer than three distinct positions within each sample, with three images taken at each specific location, all using a magnification of × 200.

2.8. Statistical analysis

The statistical analysis was conducted using IBM SPSS Statistics software version 26 (IBM Corp., USA). The outcomes were presented as mean values with their corresponding standard deviations and were subsequently subjected to a one-way analysis of variance (ANOVA), followed by a Duncan test ($p < 0.05$).

3. Results and discussion

3.1. Effect of convective drying on black rosehip phenolic acids and flavonoids

Food processing can cause positive, neutral, and negative changes in the preservation of fruit and vegetable phenolic compounds. As seen in this study, the individual phenolic composition of the fruit changed during drying (Table 1). The black rosehip fruit contained 2.3–20.8 mg/kg DW (dry weight) fumaric acid, 7.3–17.3 mg/kg DW gallic acid, 3.9–38.5 mg/kg DW protocatechuic acid, 486–1100 mg/kg DW catechin, 4.5–7.1 mg/kg DW chlorogenic acid, 51.2–172.5 mg/kg DW epicatechin, 36.6–59.4 mg/kg DW quercetin-3-glucoside, 9.6–35.0 mg/kg DW quercetin, and 10.6–26.0 mg/kg DW quercetin-3-rutinoside. The drying process has been shown to lead to an increase in the concentration of specific phenolic compounds. This outcome is attributed to the potential effects of both thermal and non-thermal drying methods, which are believed to aid in the preservation of bioactive compounds. Furthermore, these drying methods may facilitate the release of compounds that are predominantly bound and associated with cell walls. These findings are consistent with previous research (Asami et al., 2003; Gao et al., 2012). Similar results were observed in a study involving corn dried at 115 °C for varying durations (Dewanto et al., 2002). Additionally, previous research documented an increase in phenolic components for tangerine waste (Esparza-Martinez et al., 2016) and cocoa (Valadez-Carmona et al., 2017), respectively, through drying processes

Table 1
Amount of phenolic acids and flavonoids of fresh (mg/kg FW) and convectively dried (mg/kg DW) black rosehip fruit at different temperatures and airflows.

Temperature, °C	Airflow, m/s	FA	GA	PCHA	C	CHA	EC	Q-3-G	Q	Q-3-R
Fresh sample	-	4.49 ± 0.05	24.0 ± 0.5	9.86 ± 0.07	1570 ± 13	29.26 ± 0.02	106 ± 1	79.1 ± 3.2	27.0 ± 0.1	10.6 ± 0.1
50	0.5	20.81 ± 1.08^{a}	14.9 ± 0.3^{b}	38.5 ± 0.4^{a}	486 ± 41^{f}	7.10 ± 0.10^{a}	51.2 ± 1.4^{i}	39.6 ± 3.0^{d}	35.0 ± 0.7^{b}	25.5 ± 0.8^{a}
	1	12.41 ± 0.07^{b}	15.0 ± 0.0^{b}	21.8 ± 0.0^{b}	1070 ± 80^{a}	5.59 ± 0.00^{ed}	103 ± 1.7^{e}	48.0 ± 2.4^{b}	41.1 ± 0.6^{a}	26.0 ± 0.0^{a}
	1.5	12.49 ± 0.17^{b}	10.7 ± 0.1^{g}	20.4 ± 0.1^{c}	842 ± 20^{cb}	5.54 ± 0.04^{e}	94.5 ± 0.2^{f}	59.4 ± 5.9^{a}	28.3 ± 0.3^{c}	21.7 ± 0.1^{edbc}
60	0.5	7.92 ± 0.08^{d}	13.2 ± 0.0^{d}	20.2 ± 0.2^{c}	863 ± 26^{cb}	4.49 ± 0.03^{h}	110 ± 0.4^{d}	48.0 ± 2.4^{b}	22.3 ± 0.4^{d}	22.0 ± 0.3^{cba}
	1	9.40 ± 0.02^{c}	12.4 ± 0.3^{e}	18.8 ± 0.1^{d}	807 ± 17^{c}	4.69 ± 0.03^{hg}	96.0 ± 0.1^{f}	50.4 ± 3.0^{b}	20.6 ± 0.1^{d}	23.3 ± 0.4^{cba}
	1.5	8.23 ± 0.06^{d}	11.3 ± 0.2^{f}	15.1 ± 0.1^{f}	724 ± 12^{d}	5.95 ± 0.36^{cb}	80.1 ± 1.7^{h}	49.3 ± 0.2^{b}	14.4 ± 2.5^{e}	23.5 ± 0.2^{ba}
70	0.5	7.05 ± 0.06^{e}	7.31 ± 0.04^{j}	15.7 ± 0.0^{f}	885 ± 24^{b}	6.90 ± 0.05^{a}	115 ± 1^{c}	41.1 ± 4.2^{de}	14.1 ± 0.0^{e}	22.3 ± 3.1^{dcb}
	1	6.09 ± 0.10^{f}	12.7 ± 0.4^{e}	15.4 ± 0.1^{f}	808 ± 20^{c}	5.27 ± 0.06^{f}	113 ± 2^{dc}	36.6 ± 0.1^{d}	11.5 ± 0.0^{hg}	20.0 ± 0.6^{ed}
	1.5	3.92 ± 0.08^{g}	9.37 ± 0.07^{i}	11.6 ± 0.0^{g}	1100 ± 26^{a}	4.79 ± 0.07^{g}	172 ± 2^{a}	38.1 ± 0.3^{d}	9.6 ± 0.1^{h}	14.6 ± 0.0^{f}
80	0.5	9.02 ± 0.04^{c}	10.0 ± 0.1^{h}	15.2 ± 0.0^{f}	565 ± 1^{e}	6.18 ± 0.09^{b}	86.5 ± 0.5^{g}	41.8 ± 1.7^{de}	13.5 ± 2.1^{gfe}	20.5 ± 2.5^{edb}
	1	3.79 ± 0.00^{g}	14.1 ± 0.0^{c}	16.4 ± 0.0^{e}	789 ± 36^{dc}	5.85 ± 0.02^{dc}	131 ± 1^{b}	46.9 ± 0.3^{cb}	13.8 ± 0.1^{e}	19.3 ± 0.5^{e}
	1.5	2.27 ± 0.12^{h}	17.3 ± 0.3^{a}	16.9 ± 0.0^{e}	804 ± 13^{c}	5.76 ± 0.01^{edc}	134 ± 3^{b}	49.4 ± 0.7^{b}	11.7 ± 0.0^{hgf}	15.2 ± 0.3^{f}

FW – Fresh weight, DW – Dry weight. There is no statistical difference between the means shown with the same letter in the same column ($p > 0.05$).

conducted at 120 and 60 °C. Similarly, a previous study by our research group demonstrated a significant increase in phenolic compounds in autumn olive berry fruits after convective hot air drying at 80 °C and 1 m/s for 180 min (Zannou et al., 2021).

It is seen that the present results are compatible with the results of these researchers. A study considering sweet potatoes reported that with drying, the cell structure was damaged and antioxidant compounds were better extracted, so phenolic compounds may increase in hot air drying (Shih et al., 2009). In addition, phenolic compounds may decrease with convective drying, which may develop as a result of the loss and oxidation of free phenolic compounds (Asami et al., 2003).

As a result of the Duncan Multiple Comparison Test based on the data obtained; airflow, temperature, and their interaction were found to be significant at the $p < 0.05$ level. According to the analysis results, the highest catechin and epicatechin values were detected at 70 °C, 1.5 m/s airflow. Fresh and dried fruits were rich in catechins, and catechin and epicatechin were the predominant phenolic compounds. Catechins are the most powerful antioxidant compounds. In addition, these fruits are important sources of quercetin and quercetin-3-glucoside, which are powerful antioxidants. These primary phenolic compounds exhibit notable biological activity and offer various advantageous impacts on human well-being. Catechin and its related derivatives are known for their biological properties, encompassing antioxidative, anticancer, anti-obesity, and hypolipidemic effects (Venkatakrishnan et al., 2019). The sample treated at 50 °C and 0.5 m/s demonstrated the highest recorded levels of chlorogenic acid, fumaric acid, gallic acid, protocatechuic acid, quercetin, and quercetin-3-glucoside.

Drying at different airflow did not affect the other compounds except the chlorogenic acid content of the fruits ($p > 0.05$). It was observed that the drying temperature affected all individual phenolic compounds ($p < 0.05$). According to the statistical analysis results, the highest values for catechin and epicatechin were in the sample treated at 70 °C. The sample dried at 50 °C exhibits the highest concentrations of chlorogenic acid, fumaric acid, gallic acid, protocatechuic acid, quercetin, and quercetin-3-glucoside.

Phenolic acids and flavonoids are known to be heat-sensitive, thus at high temperatures, these compounds can undergo degradation. Although degradation could decrease the amount of these compounds, it could sometimes have a positive effect on the antioxidant activity of the fruit (Maghsoudlou et al., 2019). Complex polyphenols may degrade into small phenolic compounds that are easily absorbed by the body and could potentially result in a higher bioavailability (Stefanescu et al., 2019).

3.2. *Effect of convective drying on black rosehip anthocyanins*

In the study, four anthocyanins (cyanine chloride, cyanide-3 glucoside, cyanidin-3 rutinoside, and pelargonidin-3 glucoside) were identified and quantified (Table 2). As seen in Table 2, the dominant pigment in fresh and dried fruits is cyanidin-3 glucoside. A large amount of cyanine chloride was also found in black rosehip fruits. This is in agreement with previous studies which determined cyanidin-3-glucoside as the dominant anthocyanin in black rosehip fruits (Odabaş and Koca, 2020; Odabaş and Koca, 2021). An investigation focusing on the pigment compounds of *Rosa* species reported that they contained high amounts of anthocyanins including cyanidin-3-glucoside, cyanidin-3,5-diglycoside, and peonidin-3-glycoside (Novruzov, 2005).

In the current study, drying affected the content of anthocyanins. While the amount of some compounds decreased, some remained stable. Higher amounts of cyanine chloride, cyanidin-3-glucoside, cyanidin-3-rutinoside, and pelargonidin-3-glucoside compounds were found in fresh fruits. It has been determined that there are losses after drying at these values. Similarly, it has been determined that the content of anthocyanin compounds decreased during the convective drying of blueberries compared to fresh fruit (Martín-Gómez et al., 2020). A study which investigated the composition of anthocyanin compounds in black

Table 2
Amount of anthocyanins of fresh (mg/kg FW) and convectively dried (mg/kg DW) black rosehip fruit at different temperatures and airflows.

Temperature, °C	Airflow, m/s	CC	C-3-G	C-3-R	P-3-G
Fresh Sample	-	1150 ± 51	12,500 ± 369	51.7 ± 4.2	79.05 ± 4.90
50	0.5	228 ± 10[e]	1010 ± 14 [g]	12.9 ± 0.5 [g]	3.47 ± 0.18[dc]
	1	187 ± 9 [f]	906 ± 1 [h]	17.2 ± 0.3[e]	2.75 ± 0.16[d]
	1.5	250 ± 2[e]	1560 ± 9[e]	16.1 ± 0.3[fe]	5.47 ± 0.68[b]
60	0.5	305 ± 7[d]	2240 ± 57[b]	29.2 ± 1.0[a]	6.19 ± 0.46[b]
	1	380 ± 9[ba]	2390 ± 99[a]	20.9 ± 0.7[c]	8.93 ± 0.64[a]
	1.5	378 ± 10[ba]	2250 ± 5[b]	20.5 ± 0.7[dc]	6.28 ± 0.23[b]
70	0.5	343 ± 17[c]	1850 ± 37[c]	26.5 ± 1.0[b]	3.80 ± 0.02[c]
	1	369 ± 18[b]	1670 ± 18[d]	17.4 ± 1.2[e]	3.67 ± 0.12[c]
	1.5	396 ± 14[a]	2470 ± 33[a]	30.0 ± 0.6[a]	8.00 ± 0.15[a]
80	0.5	363 ± 1[cb]	1640 ± 17[ed]	18.2 ± 1.1[ed]	4.04 ± 0.07[c]
	1	292 ± 2[d]	1470 ± 6 [f]	17.5 ± 1.2[e]	3.16 ± 0.57[dc]
	1.5	369 ± 10[b]	1670 ± 39[d]	14.1 ± 2.8[gf]	3.82 ± 0.15[c]

FW – Fresh weight, DW – Dry weight. There is no statistical difference between the means shown with the same letter in the same column ($p > 0.05$).

carrots dried with five different drying methods reported that anthocyanin compounds decreased as a result of the drying process compared to fresh fruit (Polat et al., 2022). The main reason for the degradation of anthocyanins has been attributed to increased oxidation reactions and cleavage of covalent bonds as a result of thermal treatment. During dehydration, anthocyanins, aldehydes, and benzoic acid by-products can be converted into smaller molecules (Zorić et al., 2014). The results determined in this study can also be explained by all these events.

As seen in Table 2, significant changes in the levels of cyanine chloride, cyanidin-3-glucoside, cyanidin-3-rutinoside, and pelargonidin-3-glucoside were observed in black rosehips during the drying process ($p < 0.05$). The dried samples showed the highest levels of cyanidin-3 glucoside, cyanine chloride, cyanidin-3-rutinoside, and pelargonidin-3 glucoside at 70 °C and 1.5 m/s. Specifically, the highest content of cyanine chloride was recorded at 70 °C, while the lowest was observed at 50 °C. Cyanidin-3-glucoside, cyanidin-3-rutinoside, and pelargonidin-3-glucoside exhibited their peak concentrations at temperatures of 60 and 70 °C. While temperature had a statistically significant impact ($p < 0.05$) on individual anthocyanins, air velocity did not demonstrate a significant effect ($p > 0.05$).

The lowest individual anthocyanins were detected at 50 and 80 °C. These low individual anthocyanins are thought to be extremely sensitive to heat at temperatures of 80 °C. A study investigating the effect of convective drying of four different fruits (black currant, red currant, raspberry, and blackberry) at three temperatures (50, 65, and 130 °C) found that the individual anthocyanin content decreased at high temperatures (Bustos et al., 2018). A previous study reported that subjecting strawberries and blueberries to high-temperature drying processes led to a reduction in their anthocyanin content (Mendez-Lagunas et al., 2017). At high temperatures, anthocyanins tend to undergo thermal degradation which results in their breakdown into other molecules. Anthocyanins could undergo glycosylation, nucleophilic attack of water, cleavage and polymerization at elevated temperatures producing other molecules (Enaru et al., 2021). These molecules may not have the same bioactivities (e.g., antioxidant capacity) as anthocyanins. Degradation of anthocyanins would also mean the possibility of colour change (e.g., losing the vibrant colour). Similarly, both the temperature and duration of heat treatment can significantly influence the stability of anthocyanins in fruits such as blueberries (Patras et al., 2010). It was determined that the composition of the anthocyanin compounds of the samples treated at 50 °C was related to the heating time. Studies have indicated that anthocyanins can undergo enzymatic degradation mediated by polyphenol oxidase (PPO) at lower temperatures. However, the activities of these enzymes, responsible for phenolic oxidation, tend to diminish as temperature levels rise (Patras et al., 2010).

3.3. *Effect of convective drying on black rosehip fruit texture*

Variations in moisture levels throughout the drying procedure prompted alterations in mechanical or textural characteristics. Evident from Table 3 is the presence of statistically significant distinctions ($p < 0.05$) in hardness, springiness, cohesiveness, gumminess, chewiness, and resilience values between the fresh and dried samples.

The hardness of black rosehip samples ranged from 44.0 to 81.3, springiness 0.75–0.88, cohesiveness 0.29–0.66, gumminess 21.3–33.6, chewiness 21.6–34.4, and resilience 0.12–0.26. The findings indicate a noteworthy augmentation in the hardness, cohesiveness, and chewiness of the samples due to hot air drying. Nevertheless, upon comparison with fresh fruit, noticeable decreases were observed in the springiness, cohesiveness, and resilience values.

As a result of the Duncan Multiple Comparison Test, hardness, springiness, cohesiveness, chewiness, and resilience values of black rosehip samples dried at different temperatures were found to be statistically different at $p < 0.05$ level, while those dried at different air velocities were found to be different. There was no difference between the groups ($p > 0.05$). According to the results obtained, hardness, springiness, cohesiveness, chewiness, and resilience were affected by temperature during drying and were statistically significant as mentioned before. While the highest values for hardness and chewiness were obtained at 70.12 and 29.38, respectively, dried fruits at 80 °C, respectively, the highest values for springiness, cohesiveness, and resilience were found at 0.81, 0.63, 0.25, respectively dried fruits at 50 °C. The softer the dried fruit, the higher the quality of the product. Hardness is an important parameter used to determine the quality of dried fruits. In a previous study, hardness and chewiness increased with increasing temperature by convective drying of chempedak at different drying temperatures (50, 60, and 70 °C); however, they reported that the springiness and cohesiveness values of dried chempedak remained relatively constant (Chong et al., 2008).

During drying, water evaporates first from the surface of the fruit and then from the inside. This results in significant shrinkage and collapsed surfaces, which lead to hard textural features (Zielinska et al., 2016). Therefore, an increase in hardness, gumminess, and chewiness values of dried black rosehip is observed. Similarly, increased firmness and chewiness have been reported in dried bananas and mushrooms (Kotwaliwale et al., 2007). This was due to the concentration of other ingredients, which increased with the removal of moisture. Similarly, a correlation between the breakdown of cell wall constituents like pectin and a notable rise in hardness during the process of sun drying has been reported (Chong et al., 2008). The dried black rosehips exhibit a decrease in springiness, which is influenced by the gelling agent of the fruit. Previous studies noted a reduction in the springiness and cohesiveness of dried mushrooms (Kotwaliwale et al., 2007) and chempedak (Chong et al., 2008). This decline in springiness and structural integrity during hot air drying has been linked to the extraction of water, particularly at higher temperatures (Chong et al., 2008).

3.4. *Effect of convective drying on black rosehip fruit microstructure*

Morphological features of fresh and dried black rosehip fruit at four different temperatures and three different air speeds were visualized by scanning electron microscopy (Fig. 1). A scanning electron microscope (SEM) was used to clearly see the effect of cellular drying on mass transfer and tissue properties and to better understand the morphological changes of the samples. When the microstructure of fresh rosehip fruits is examined, it is seen that they consist of a large number of cell compartments and have intercellular spaces. The oval cells in the fruit tissue of the fresh rosehip can be seen very clearly. The temperature and air speeds used in drying caused significant changes in fruits. Cells are deformed, and intercellular spaces are irregular and wrinkled. The degree of deformation changed according to the temperatures. While the cell walls of the samples dried at 50 and 60 °C were more deformed, the cell walls of the samples exposed to 70 and 80 °C and dried in a short time were less damaged. SEM micrographs clearly show that drying temperature and time strongly influence the microstructure of dried samples. In fact, some capillaries are not closed. Earlier research has documented that utilizing high-temperature air for drying induces significant tissue shrinkage and collapse (Giri and Prasad, 2007; Zannou et al., 2021). Additionally, it has been noted that the drying process can result in notable deterioration, deformation, and folding of cellular structures, possibly attributed to thermal degradation, loss of moisture, and denaturation of specific chemical constituents, particularly polysaccharides (Deng and Zhao, 2008; Giri and Prasad, 2007).

4. Conclusions

Fresh and dried black rosehip fruit abound in catechins, with catechin and epicatechin standing out as the predominant polyphenols. The highest levels of catechin and epicatechin were observed at 70 °C with airflows set at 1.5 m/s. In terms of anthocyanins, the prevailing pigment in both fresh and dried fruits was found to be cyanidin-3-glucoside. Throughout the drying process, the composition of anthocyanin compounds within the fruits changed. While the quantities of certain

Table 3
Texture properties of fresh and convectively dried black rosehip fruit at different temperatures and airflows.

Temperature, °C	Velocity, m/s	Hardness, N	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
Fresh Sample	-	44.0 ± 0.6^{e}	0.88 ± 0.00^{a}	0.71 ± 0.03^{a}	15.9 ± 2.4^{c}	12.8 ± 1.7^{e}	0.37 ± 0.02^{a}
50	0.5	50.0 ± 0.1^{d}	0.81 ± 0.02^{dcb}	0.66 ± 0.00^{ba}	26.9 ± 1.3^{ba}	23.2 ± 2.6^{dcb}	0.26 ± 0.01^{b}
	1	50.5 ± 0.7^{d}	0.80 ± 0.01^{dcb}	0.62 ± 0.02^{ba}	31.3 ± 0.8^{a}	25.2 ± 0.4^{dcb}	0.24 ± 0.01^{b}
	1.5	50.9 ± 2.0^{d}	0.81 ± 0.00^{dcb}	0.62 ± 0.05^{ba}	31.6 ± 2.9^{a}	25.9 ± 2.2^{dcb}	0.24 ± 0.02^{b}
60	0.5	49.9 ± 0.6^{d}	0.82 ± 0.07^{dcb}	0.45 ± 0.01^{d}	21.8 ± 3.8^{cb}	22.4 ± 1.5^{dc}	0.16 ± 0.03^{dc}
	1	50.5 ± 0.7^{d}	0.82 ± 0.04^{cba}	0.45 ± 0.02^{d}	21.9 ± 2.8^{cb}	22.0 ± 1.2^{dc}	0.16 ± 0.02^{dc}
	1.5	55.4 ± 0.6^{c}	$0.81 \pm 0.00d^{cb}$	0.62 ± 0.05^{ba}	31.6 ± 2.9^{a}	25.9 ± 2.2^{dcb}	0.24 ± 0.01^{b}
70	0.5	54.7 ± 0.4^{c}	0.83 ± 0.00^{ba}	0.56 ± 0.02^{cb}	33.6 ± 3.2^{a}	21.6 ± 2.2^{d}	0.26 ± 0.00^{b}
	1	56.1 ± 0.7^{c}	0.79 ± 0.01^{dcb}	0.48 ± 0.12^{dc}	27.0 ± 5.7^{ba}	21.9 ± 0.8^{dc}	0.18 ± 0.05^{c}
	1.5	65.0 ± 3.3^{b}	0.82 ± 0.00^{cba}	0.61 ± 0.00^{ba}	31.3 ± 0.0^{a}	23.2 ± 0.7^{dcb}	0.24 ± 0.00^{b}
80	0.5	64.1 ± 0.5^{b}	0.75 ± 0.03^{dc}	0.33 ± 0.05^{e}	21.4 ± 2.5^{cb}	27.5 ± 2.7^{b}	0.13 ± 0.02^{d}
	1	81.3 ± 0.5^{a}	0.75 ± 0.04^{dc}	0.29 ± 0.02^{e}	27.3 ± 0.7^{ba}	26.3 ± 0.8^{cb}	0.12 ± 0.01^{d}
	1.5	44.0 ± 0.6^{e}	0.81 ± 0.00^{dcb}	0.38 ± 0.01^{ed}	31.4 ± 0.9^{a}	34.4 ± 2.6^{a}	0.16 ± 0.00^{dc}

There is no statistical difference between the means shown with the same letter in the same column ($p > 0.05$).

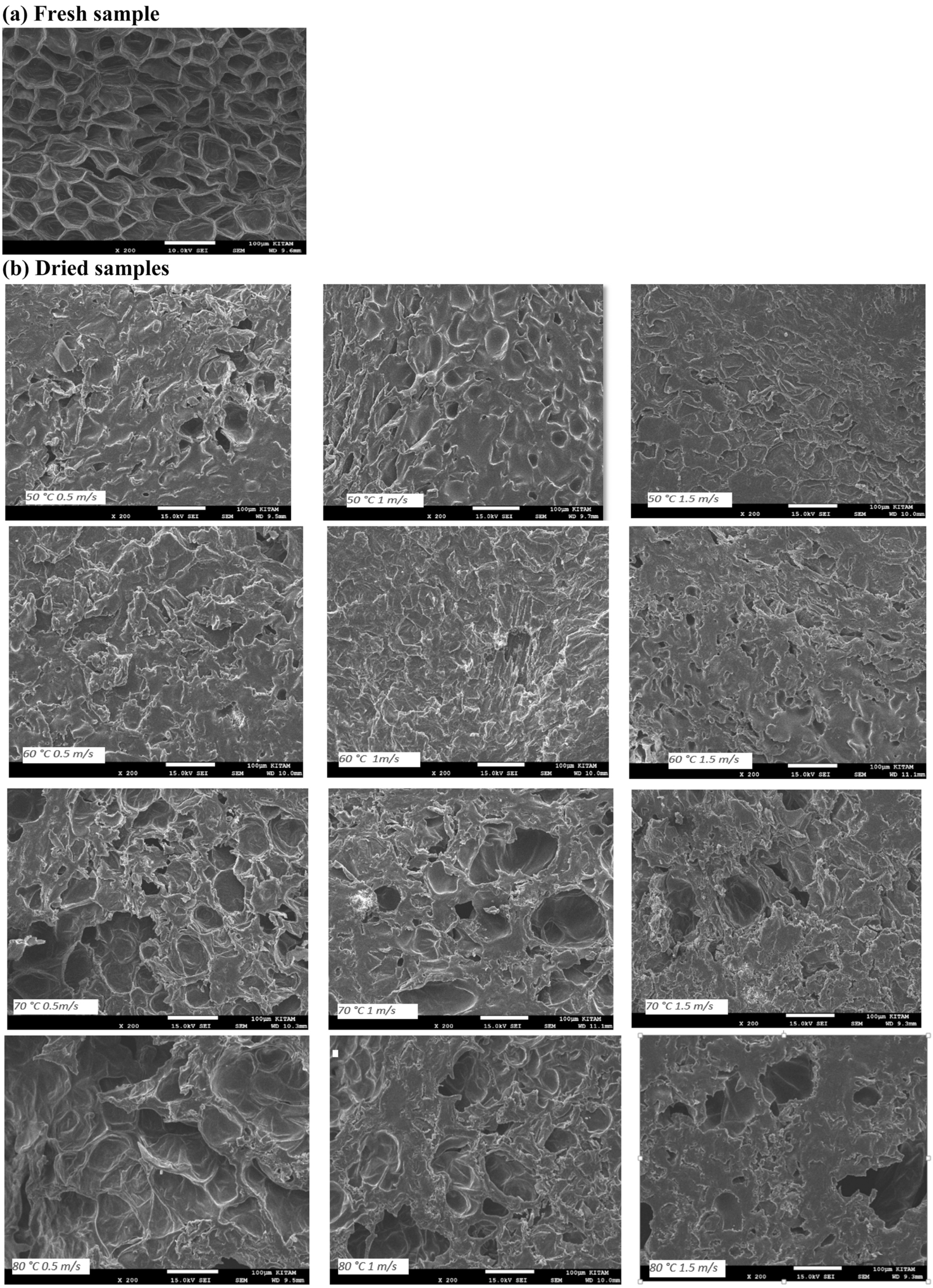

Fig. 1. SEM images of (a) fresh and (b) convectively dried fruit samples at different temperatures and air flows.

compounds decreased, others remained constant. The highest amounts of cyanidin-3-glucoside and cyanine chloride, along with cyanidin-3-rutinoside and pelargonidin-3-glucoside, were determined in samples subjected to drying at 70 °C with airflows at 1.5 m/s. While temperature exerted a notable influence on individual anthocyanins, airflow demonstrated an insignificant effect.

In terms of texture, the hardness, springiness, cohesiveness, gumminess, chewiness, and resilience values of fresh and dried fruits were statistically different from each other. Drying with hot air significantly increases the hardness, cohesiveness, and chewiness of the samples. However, when compared to fresh fruit, springiness, cohesiveness, and strength were relatively decreased. In relation to microstructure, fresh rosehip fruits are comprised of numerous cellular compartments and possess intercellular spaces. The applied drying temperatures and air velocities induced substantial alterations in the fruit structure. Cell wall deformations were more pronounced in samples dried at 50 and 60 °C, whereas those subjected to 70 and 80 °C, and subsequently dried for shorter durations, exhibited lesser degrees of cell wall damage. Considering these effects of drying on the matrix, future research could investigate the effect of these factors on the bioaccessibility and bioavailability of phenolic acids, flavonoids and anthocyanins of dried black rosehip fruit.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

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CRediT authorship contribution statement

Hojjat Pashazadeh: Conceptualization, Methodology, Investigation, Software, Data curation, Writing – original draft. **Ali Ali Redha:** Validation, Writing – original draft, Writing – review & editing. **Ilkay Koca:** Conceptualization, Methodology, Supervision, Project Administration, Writing – review & editing.

Declaration of Competing Interest

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

Availability of data and materials

Data available within the article or its supplementary materials.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jfca.2023.105738.

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