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ORIGINAL PAPER

Comparison of physicochemical and biochemical analysis of aronia powders conversed by microwave and hybrid systems

Muhammed Taşova[1] · Muhammed Rahmetullah Çiğdem[2] · Samet Kaya Dursun[1] · Onur Saraçoğlu[2]

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Abstract

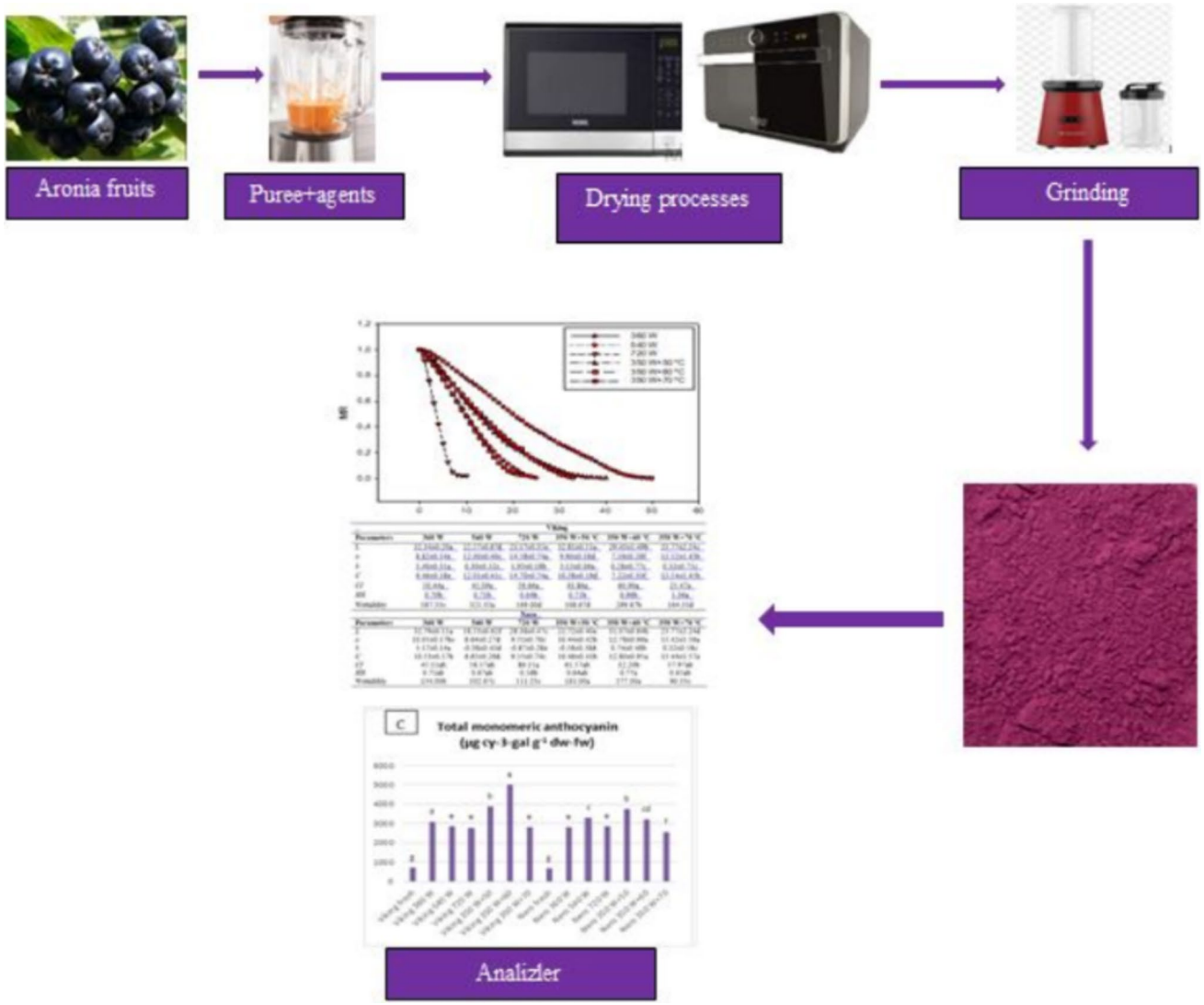
In this study, determining the physical and chemical properties of the powders obtained by producing fruit powder from the Viking and Nero varieties of aronia fruit and it was aimed to determine which drying method is more suitable in terms of both quality and energy in the production of aronia fruit powder. The highest drying rate values were determined in Nero variety with $6.02\times10^{-2}-3.05\times10^{-1}$ g moisture/g dry matter min. The effective moisture diffusion values of the Viking cultivar varied between 4.30×10^{-7} and 2.53×10^{-6} m^2s^{-1}. The lowest activation energy value was determined as 35.87 kJ/mol in the MACD method in the Viking variety. The best carr index values were determined when dried at 350W + 70 °C drying conditions and the carr index value of the fruit powders was in the "poor" category. The best hausner index value was found to be at the "excellent" level. The *L*, *a* and *b* values of Viking and Nero varieties were numerically affected by the drying processes. The highest chroma value for both varieties was determined in the 350W + 70 °C method. The specific moisture absorption rate and specific energy consumption values of the Nero cultivar were found to vary between 6.04×10^{-3}–1.59×10^{-2} kg/kWh and 62.68–165.43kWh/kg. In the Viking variety, total phenol, monomeric anthocyanin, and antioxidant contents range from 9.366 mg GAE g^{-1} fw to 37.667 mg GAE g^{-1} dw, 0.712 mg g^{-1} fw to 4.985 mg g^{-1} dw, 6.12 µmol TE g^{-1} fw to 272.41 µmol TE g^{-1} dw. The total flavonoid content in the Nero variety ranges from 1.597 g CE L^{-1} fw to 19.184 g CE L^{-1} dw.

✉ Muhammed Taşova
muhammed.tasova@gop.edu.tr

[1] Department of Biosystems Engineering, Faculty of Agriculture, Tokat Gaziosmanpaşa University, 60250 Tokat, Turkey

[2] Department of Horticulture, Faculty of Agriculture, Tokat Gaziosmanpaşa University, 60250 Tokat, Turkey

Graphical abstract



Keywords Powder technology · Drying processes · Physical · Phytochemical · Energy consumption

Introduction

Aronia melanocarpa is a perennial shrub-shaped berry fruit species in the genus Aronia in the family Rosaceae, order Rosales. Originally from the eastern part of North America and eastern Canada, it has been cultivated commercially in Russia since the first half of the 20th century and in Eastern Europe, especially in Germany, since the second half of the 20th century. Today, it is grown almost all over the world (Kulling and Rawel 2008; Ochmian et al. 2012; Borowska and Brzóska 2016; Akdemir 2022). The first studies on aronia cultivation in Turkey started in 2012 with the production of saplings at Atatürk Horticultural Cultures Central Research Institute and a plantation was established in the trial area. In 2017, commercial cultivation was started (Ministry of Agriculture and Forestry (MoAF 2022). 'The more important cultivars include Nero (Czechia), Rubina (crossing from Russian and Finnish plants), Viking (Finland), Kurkumäcki (Finland), Hugin (Sweden), Fertödi (Hungary) and Aron (Denmark). Viking and Nero are cultivars that are commonly available in North American plant catalogs' (Kulling and Rawel 2008). Aronia fruits are consumed for syrup, fruit juice, soft spreads, fruit jellies, tea, jams, wines, liqueurs, schnapps, nectars, preserves, tinctures, fruit desserts, and dietary supplements (Kulling and Rawel 2008; Jurendić and Ščetar 2021; Akdemir 2022). Mature aronia

fruits can be 6–13 mm in diameter and 0.5–2 g in weight. It has been reported that the water soluble dry matter content of the fruits varies between 12 and 20%, titratable acid content determined in citric acid between 0.7 and 1.4%, and pH value between 3.3 and 3.7 (Ochmian et al. 2012; MoAF, 2022). Aronia has a very high polyphenol content such as phenolic acids, proanthocyanidins, anthocyanins, flavonols, and flavanones, consequently, high antioxidant capacity values. The presence of these polyphenols is responsible for many medicinal properties of aronia (Oszmiański and Wojdylo 2005; Kulling and Rawel 2008; Ochmian et al. 2012; Symonowicz et al. 2012; Borowska and Brzóska 2016; Jurendić and Ščetar 2021). According to a study, daily supplementation of aronia fruit extracts for 6–8 weeks was reported to significantly reduce total cholesterol as well as systolic blood pressure, an important risk factor for cardiovascular disease (Hawkins et al. 2021).

Medicinal and aromatic fruits are used in many fields, especially in the pharmaceutical industry and food industry. After harvesting, microbiological deterioration occurs very rapidly due to the high respiration rate of these fruits. This causes quality losses and shortens the shelf life (Ferrari et al. 2012). Fruits are highly perishable foods due to their high water content and are generally processed into dried products for several reasons as prolonging their shelf life, enhancing storage stability, consumption after the seasons, and reducing transport weight (Kara and Doymaz 2015). One of the processes that provide functional properties is fruit powder production. While the commercial value of the products converted into powder increases, it provides convenience in stages such as transport and storage by reducing weight and volume. In addition, powdered products are easier to process (Majid and Nanda 2017), their taste and aroma are intensified and their use is enabled. Fruit and vegetable powder production is increasing day by day on a global scale. According to 2017 data, the global market value of only fruit powder is estimated to be 13.52 million dollars and this value is estimated to increase by 7.40% until 2025 and rise to approximately 14.52 million dollars. It is stated that the powders produced are widely used in foods, baby biscuits, bakery products, and snack products (Hexa Research 2018; Turkiewicz et al. 2020). Drying is briefly the process of removing moisture content from the fresh product. This process aim is to prevent spoilage that may occur as a result of enzymatic reactions and to preserve the aroma, taste, and color properties of the products in this process (Bonazzi and Dumoulin 2011). Open drying (sun–shade) is the oldest known drying method. Although it provides significant advantages in terms of environment and cost, sun drying has some disadvantages because it cannot be carried out at all times of the year, large areas are needed, it cannot be reduced to the desired moisture level and it is adversely affected by environmental effects (dust, rain, wind, insects, birds, etc.) (Purohit et al. 2006; Sharma et al. 2009; Taşkın et al. 2021). Another method widely used in the drying industry is the conventional artificial drying method. This method has some disadvantages such as initial installation cost and high energy consumption values. The convective drying method provides a more homogeneous heat distribution in the product compared to open drying, drying faster and better quality end products can be obtained (Morais et al. 2018; Yan et al. 2019; Boateng and Yang 2020). Another drying method that has recently become popular is microwave drying. In the drying process with this method, unlike the hot air drying process, the rays produced by the dryer enter the product and diffuse the moisture it contains from the inside outwards. This leads to a decrease in drying time and less energy consumption (Yılmaz and Alibaş, 2021). Another drying method that has recently become popular is the hybrid (microwave + convective) drying method in which microwave and convective dryers are combined. It is reported that the energy consumption values realized in drying processes are high. It is known that an average of 10–25% of the total energy consumption of the countries is consumed only in the drying industry and processes (Mujumdar and Law 2010). For this reason, it is important to develop different techniques to reduce energy consumption in drying processes to both reduce the cost of fruit powder production and to be sustainable. In the literature on powder production; Fazaeli et al. (2013) studied the conversion of black mulberry juice into powder by drying with convective and microwave methods. It was reported that the losses of anthocyanin and antioxidant substances occurring in the convective method were higher than the microwave drying method. Jiang et al. (2015) applied thermal, microwave, and ultrasound pretreatments to black mulberry juice and stored it for 2 months. They found that the samples treated with thermal method had temporarily high antioxidant activity for a short period compared to the samples treated with microwave and ultrasound methods. However, they reported that the samples with thermal pretreatment had the lowest antioxidant activity at the end of storage. Elik et al. (2016) investigated the effect of microwave, vacuum and open drying processes on blueberry fruit juice. They determined that the least changes in L, a, and b values of the samples were in the microwave drying method and reported that the least loss in anthocyanin values was also in the microwave drying process. Marszałek et al. (2015) applied convective and microwave heat treatments to strawberry puree and investigated the changes in the quality characteristics of the product. They found that the vitamin C, polyphenol and anthocyanin values of the samples processed by the convective method were higher than the samples processed by the microwave heat method. Wang et al. (2020) conducted a study to convert black mulberry juice into powder by spray drying technique. They investigated the effects of maltodextrin, whey,

pea, soya, and egg albumin proteins on the physical quality properties of the powder. Within the scope of the study, they found that the use of maltodextrin was better than the others in terms of water soluble index, hygroscopicity, and color change parameters. Braga and Rocha (2015) examined the physicochemical properties, anthocyanin content, and deterioration during storage of the powder for 140 days by adding maltodextrin, casein, and palm oil at different ratios to a mixture of blackberry puree and whole milk. As a result of the study, while the best powder quality was obtained in the mixture of 25% milk and 75% blackberry puree, maltodextrin, casein and palm oil added to the concentrated milk blackberry puree did not increase the powder production efficiency. In a 140-day storage period, they observed that anthocyanin degradation was significant. Nogueira et al. (2020) investigated the effect of spray drying on the bioactive compounds of microencapsulated blackberry puree of arrowroot starch and gum Arabic mixtures. Within the scope of the study, they determined that the inlet air temperatures and encapsulant concentrations used during the spray drying process affect the bioactive compounds of the powder ($p < 0.05$). They observed that the mixture of arrowroot starch and gum Arabic was effective on the ascorbic acid content and particle formation of the powders. As a result, they reported that the most ideal condition for producing blackberry powders with high ascorbic acid, anthocyanin, and antioxidant properties was formed with a 1/1.78 ratio of arrowroot starch–gum Arabic mixture at 143 °C temperature. In the literature review, no comprehensive study on the production of aronia powder was found in which the effects of different aronia cultivars, different drying systems and different drying conditions on the physicochemical, bioactive, drying kinetics, and energy analyses of the powder produced under different drying conditions were investigated. In this respect, the study is unique from the literature.

The aim of this study is to dry Viking and Nero variety aronia fruits into powder by microwave (360, 540, 720 W) and hybrid (350W + 50 °C, 350W + 60 °C, 350W + 70 °C) methods. To investigate the effects of drying methods and fruit cultivar on the drying rate, moisture rate, effective moisture diffusion, specific moisture absorption rate, specific energy consumption, color values, moisture content, Carr–Hausner indices, wettability, bulk–tapped density properties, hygroscopicity and bioactive properties of the produced powders.

Material and methods

Raw material and chemical agents

Fresh Viking and Nero cultivar aronia fruits used to produce powder were harvested in September/2023 from the garden of the research institute in Tokat/Turkey. The Viking and Nero cultivar aronia fruits samples were stored at 4 ± 0.5 °C in refrigerator conditions until the end of the study. The fruits to turn into powder, Parmor Consultancy Marketing Import Export Industry. The Parmor brand maltodextrin ($C_{12}H_{22}O_{11}$) agent produced by Limited Company (Turkey) was used. All chemicals required for bioactive analyses were obtained from Merck KGaA (Germany).

Sample preparation

To prepare the fruit purees, firstly, non-homogeneous colored fruits in the fresh mass were removed. After the fruit were thoroughly washed with tap water, they were kept in an open environment for a while to dry their rough water. While aronia fruit was pureed, Waseem et al. (2022) and was diluted with distilled water at a ratio of 1:5, with minor changes made. The mixture was processed for 1 min with a Waring brand HGB2WTG4 model glass blender. The blender has 220–240 V and 50–60 Hz, (400W) features. Then, 5% maltodextrin was added to the prepared puree and mixed with a hand blender for 1.50 min. The dried samples were pulverized for 2 min in a Beko brand 2166 model (700W) food processor.

Moisture determination of puree

To determine the initial moisture content of the prepared aronia fruit purees, it was set to 70 °C (Kaveh et al. 2018) and dried in a drying oven (Şimşek Laborteknik brand-ST-055 model) until the weight change was constant. The total moisture content of the samples was determined by Kaveh et al. (2018), and calculated according to the method.

Drying processes

The prepared purple cabbage purees were dried with microwave (MD) and microwave assisted convective drying (MACD) systems.

Microwave drying (MD)

Vestel brand MD-GD23 model microwave oven is used. The microwave oven has a total output power of 900W and its dimensions are height × width × depth, respectively, 305 mm × 508 mm × 385 mm. The products were dried on a rotating glass dish in the oven.

Microwave assisted convective drying (MACD)

Ariston Hotpoint Brand MWHA 33343 model 2450 MHz (Italy) was used as the hybrid drying oven used in this study. This dryer is a device with both hot air and microwave

features. The AND brand GF-300 model precision balance (0.01 g) was used to follow the weight change of the samples in the drying processes.

Drying rate (DR)

Equation 1 was used to calculate the drying rate of purees (Doymaz et al. 2006).

$$\frac{M_t - M_{(t+dt)}}{dt} \tag{1}$$

Here: *Mt* moisture content at time t (g moisture/g dry matter), *dt* minutes, *DR* drying rate (g moisture/g dry matter).

Moisture rate (MR)

Equation 2 was used to determine the rates of moisture removed from the purees (Maskan 2000).

$$MR = \frac{M - M_e}{M_0 - M_e} \tag{2}$$

Here*: MR* Moisture rate, *M* The instant moisture content of the product (g moisture/g dry matter), M_e; The equilibrium moisture content of the product (g moisture/g dry matter), M_o The initial moisture content of the product (g moisture/g dry matter).

Effective moisture diffusion value

In the drying processes, it measures the amount of the area where the moisture, which is explained by the second law of Fick's law, spreads away from the products depending on the time. When calculating the effective diffusion value, it is assumed that the tissue structure of the product is preserved and the moisture is removed from the environment only by diffusion. This value was calculated using equation number 4 (Crank 1979; Türker and İşleroğlu 2017).

$$MR = \frac{M - M_e}{M_{0-}M_e} = \frac{8}{\pi}\sum_{n=0}\frac{1}{(2n+1)^2}\exp\left[(2n+1)^2\frac{2}{4}\frac{D_{ff^t}}{L^2}\right] \tag{3}$$

$$InMR = In\frac{8}{\pi^2} - \frac{\pi^2 D_{eff^t}}{4L^2} \tag{4}$$

Here; D_{eff} effective diffusion value (m^2s^{-1}), L half of the slice thickness (m) of the product. t indicates the drying time of the product.

Activation energy value

The activation energy calculated using the Arrhenius equation shows the change in the effective diffusion value of the product depending on the temperature (Karel and Saguy 1991). This function is calculated using equations number 5and 6.

$$D_{eff} = D_0 \exp\left(-\frac{E_A}{RT}\right) \tag{5}$$

$$D_{eff} = D_0 \exp\left(-\frac{E_{A\times m}}{P}\right) \tag{6}$$

Here; D_0 Value is the diffusion coefficient (m^2/s), R Value is the gas constant (8.3143 kJ/molK), E_a The activation energy value (kJ/mol), T The drying air temperature (Kelvin), m Evaporated moisture (g), P Microwave energy (W).

Total energy consumption value

Polaxtor brand PLX-15366 model energy analyzer (±0.02 kWh) was used to measure the energy consumption values of the drying processes.

Specific moisture absorption rate (SMER)

Equation 6 was used to calculate the specific moisture absorption rates of drying processes (Surendhar et al. 2019).

$$SMER = \frac{\text{Evaporating moisture}(kg)}{\text{Consumption energy}(kWh)} \tag{6}$$

Here: SMER specific moisture extraction rate (kg/kWh).

Specific energy consumption (SEC)

Equation 7 was used to calculate the specific energy consumption (kWh) of the drying processes (Motevali et al. 2012).

$$SEC = \frac{E_t}{m_w} \tag{7}$$

Here: SEC specific energy consumption (kWh/kg moisture), E_t total consumed energy (kWh), m_w the amount of moisture removed (kg).

Moisture content of the powder

It is important to store the produced purple cabbage powder without spoiling the final moisture value. The moisture content of the powder Kaveh et al. (2018), was determined according to the method. Moisture rates of pumpkin powder samples produced were determined using equation number 10.

$$N_{d.w.} = \frac{\text{Initial weight} - \text{Last weight}}{\text{Last weight}} \times 100 \quad (10)$$

Here: Initial weight: Initial weight of powder (g), Last weight: Last weight for powder (g).

Tapped–bulk density

Tapped–bulk density values are an important volume weight value for the storage of functional food powders. The tapped and bulk density values of the produced purple cabbage powders were determined by making a minor modification to the method specified in the study of Sejali and Anuar (2011). The Tapped density (P_t) value was calculated by filling a 100 ml glass tape measure with purple cabbage powder three times and determining its weight. The bulk density (P_b) value was calculated by placing 10 g of purple cabbage powder on a 100 ml glass tape measure three times and determining the volume value (Sejali and Anuar 2011).

Flow properties

Flow property is important in pulverizing, transporting, and storing purple cabbage powders. Powder products have two basic flow characteristics. These are the Carr index (CI) and Hausner (HR) index values. The Carr index shows the pourability of the powder. The Hausner index shows the stickiness value of the powder. Equations 11 and 12 were used to calculate the carr and hausner indices of the produced powder, respectively (Asokapandian et al. 2016).

Carr index

$$\text{CI} = \frac{Pt - Pb}{Pt} \times 100 \quad (11)$$

CI index;

1) $\%0 < \text{CI} \leq \%\ 10$
   The pourability of purple cabbage powder is excellent.
2) $\%10 < \text{CI} \leq \%\ 15$
   The pourability of purple cabbage powder is good.
3) $\%15 < \text{CI} \leq \%\ 20$
   The pourability of purple cabbage powder is fair.
4) $\%20 < \text{CI} \leq \%\ 25$
   The pourability of purple cabbage powder is passable.
5) $\%25 < \text{CI} \leq \%\ 31$
   The pourability of purple cabbage powder is poor.
6) $\%31 < \text{CI} \leq \%\ 37$
   The pourability of purple cabbage powder is very poor.
7) $\%37 < \text{CI}$
   The pourability of purple cabbage powder is very very poor.

Hausner index

$$\text{HR} = \frac{Pt}{Pb} \quad (12)$$

HR index;

1) $1 < \text{HR} \leq 1.11$
   The stickiness of purple cabbage powder is excellent.
2) $1.11 < \text{HR} \leq 1.18$
   The stickiness of purple cabbage powder is good.
3) $1.18 < \text{HR} \leq 1.25$
   The stickiness of purple cabbage powder is fair.
4) $1.25 < \text{HR} \leq 1.34$
   The stickiness of purple cabbage powder is passable.
5) $1.34 < \text{HR} \leq 1.45$
   The stickiness of purple cabbage powder is poor.
6) $1.45 < \text{HR} \leq 1.59$
   The stickiness of purple cabbage powder is very poor.
7) $1.59 < \text{HR}$
   The stickiness of purple cabbage powder is very very poor.

Here; CI: Carr index (%), HR: Hausner index, P_t: Tapped density (g/ml), P_b: Bulk density (g/ml).

Color value

CR400 model/Japan color measuring device was used to measure the brightness (L), red/green (a) and yellow/blue (b) values of aronia purees and powders. The measured values are laboratory measurement values and chroma and total color change values were calculated by using equation 13 and 14. While the chroma value indicates the color tone of the product, low-quality products are calculated for pale products; while, high values are calculated. The total color change value shows the total change of color pigments that are decomposed by heat (non-enzymatic) in drying processes. The calculated color values are more important in terms of their commercial value and decision-making for the consumer. The following equations were used to calculate these values Ramallo and Mascheroni (2012).

$$\text{Croma} \quad C = (a^2 + b^2)^{1/2} \quad (13)$$

Hygroscopicity

To determine the hygroscopicity property of the aronia powders, Garofulić et al. (2016) made a small modification to the method specified in their study. Equation 14 was used to determine the hygroscopicity values of aronia powders.

$$\text{Hygroscopicity } (g/100\,g) = \left(\frac{M_2 - M_1}{M_1}\right) \times 100 \quad (14)$$

Here; M_2 represents the weight of the powder after dehumidification (g), and M_1 represents the weight of the powder in the dry state (g).

Wettability

The wettability value was determined according to the method specified by Gong et al. (2008).

Bioactive analyzes

The total phenol, flavonoid, anthocyanin and antioxidant activity analyzes were performed in dried aronia samples.

Total phenolic content

Total phenolic content was measured according to the procedure described by Singleton and Rossi (1965). The absorbance values of the extracts were measured at 750 nm in an automated UV–vis spectrophotometer (Model T60U, PG Instruments). Results are expressed as microgram (mg) gallic acid equivalent (GAE) g^{-1} dry weight (dw) and fresh weight (fw).

Total flavonoid content

Total Flavonoid content was measured according to the procedure described by Zhishen et al. (1999). The absorbances were recorded at wavelengths of 510 nm. Results are expressed as milligram (g) catechin equivalent (ce)L^{-1} dry weight (dw) and fresh weight (fw).

Total anthocyanins

Total anthocyanins were measured according to the procedure described by Giusti and Wrolstad, (2005). The absorbance was recorded at wavelengths of 533 nm and 700 nm for pH 1.0 and pH 4.5 solutions. Absorbances were calculated with the formula [(A533–A700) pH 1.0- (A533–A700) pH 4.5]. Results are expressed as microgram (µg) cyanidin-3-galactoside g^{-1} dry weight (dw) and fresh weight (fw) (Oszmiański and Wojdylo 2005). ε = molar absorbance (Cyd-3-gal 30 900). MW = anthocyanin molecular weight (Cyd-3-gal 445.2).

Total antioxidant activity

Total antioxidant activity was measured according to the procedure described by Ozgen et al. (2006). The absorbances were recorded at wavelengths of 734 nm. Results are expressed as µ mol Trolox equivalent (TE) g^{-1} dry weight (dw) and fresh weight (fw).

Statistical analysis

For statistical analysis of color, physicochemical and bioactive properties of produced aronia fruit powders Duncan multiple comparison tests ($P < 0.05$) was performed in the SPSS17 program. The SigmaPlot10 program was used to create the curves of the parameters.

Results and discussion

Moisture and drying rates

The drying curves of aronia powders produced with MD and MACD drying systems are given in Fig. 1.

According to Fig. 1, the drying processes for the Viking cultivar were dried from 3.22 to 0.01 g moisture/g dry matter value, and the drying processes for the Nero cultivar were dried from 2.99 to 0.01 g moisture/g dry matter value. In a study by Taskın (2020), it was reported that the initial moisture content of aronia fruits sliced in different shapes was dried from 3.30 to 0.01 g moisture/g dry matter value in the freeze drying method. Drying methods affected the drying kinetics values of Viking and Nero cultivar aronia fruit powders. Similarly, Marko et al. (2019) reported that drying temperatures affected the drying rate values of aronia fruit. In all drying conditions, the Nero cultivar dried in a shorter time than the Viking cultivar. This may be due to the lower initial moisture content of the Nero cultivar compared to the Viking cultivars. The drying time of Viking cultivar by MD and MACD methods varied between 51 and 11 min depending on the drying conditions. For the specified drying processes, the Nero cultivar dried in times ranging between 50 and 10 min. The increase in microwave power values for the MD method and drying temperatures for the MACD method increased the drying rate of the product and decreased the drying time. In the MACD drying process, the use of the convective method as a support to the microwave drying method had an increasing effect on the drying rate of the product. Tao et al. (2021) reported that the drying rate increased and the drying time decreased when ultrasound support was applied to the drying process in their blackberry fruit drying study with and without ultrasound support. Petković et al. (2020) reported that the drying rate increased with increasing temperature value in aronia fruit dried by convective method at 50, 60, and 70 °C. However, the lowest drying time was

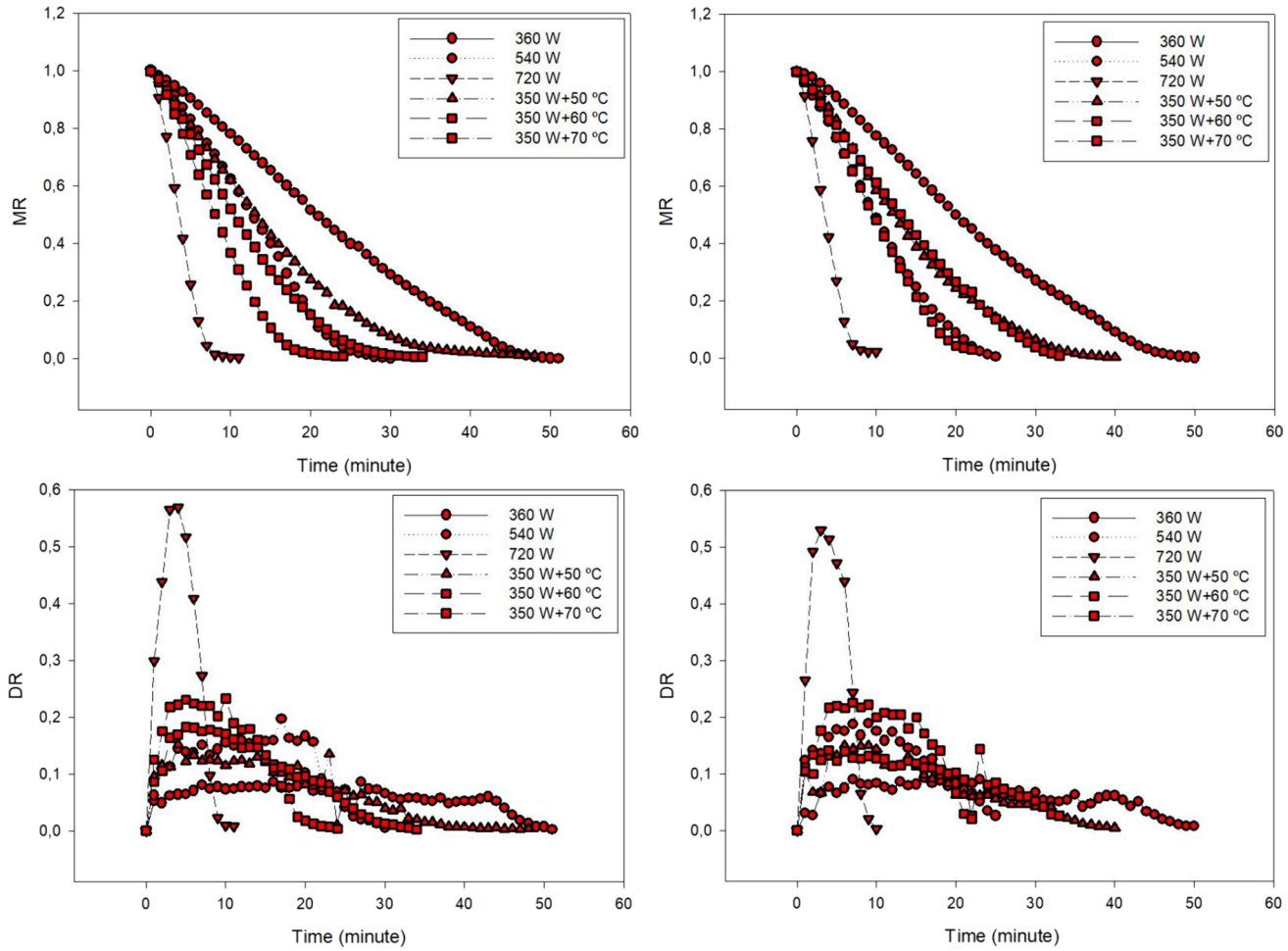


Fig. 1 Drying properties

determined in the drying process at 70 °C. The average drying rate values determined when Viking cultivar aronia fruit was dried by MD and MACD methods varied between 5.95 and 29.20×10^{-2} g moisture/g dry matter and 6.63–13.31×10^{-2} g moisture/g dry matter, respectively. The average drying rate values determined for the Nero cultivar varied between 6.02 and 30.47×10^{-2} g moisture/g dry matter and 7.43–16.42×10^{-2} g moisture/g dry matter for MD and MACD methods, respectively. In a study with blackberry fruit, Sozzi et al. (2021) found that drying processes at 50, 60, and 70 °C temperatures ranged between 0 and 4 g moisture/g dry matter and reported that the drying rate increased with increasing drying temperature. However, it is understood from the graphs that the drying rate is generally concentrated below 0.01 g moisture/g dry matter value in the drying process at 50 °C. It was observed that the findings in the literature and the findings obtained in this study were compatible with each other. It is thought that the small differences between the findings are due to the different materials.

Effective diffusion activation energy values

The effective diffusion and activation energy values of Viking and Nero cultivar *Aronia* purees are given in Table 1.

According to Table 1, it was observed that drying methods and drying conditions affected on the effective and moisture diffusion values of Viking and Nero cultivar aronia fruit purees. In the literature, Görgüç et al. (2022) stated that drying processes affect the effective moisture diffusion and activation energy values of aronia fruits subjected to high power ultrasound pretreatment. Effective moisture diffusion values varied between 4.30×0^{-7} and 2.53×10^{-6} $m^2\ s^{-1}$ in the Viking cultivar and between 4.00×10^{-7} and $1.89 \times 10^{-6} m^2\ s^{-1}$ in the Nero cultivar. In other studies, Filipović et al. (2020) reported that the effective moisture diffusion values of drying processes performed at increasing temperatures between 50 and 70 °C ranged between 2.93 and 7.77×10^{-6} $m^2\ s^{-1}$. Petković et al. (2023) dried aronia fruit by conventional hot air and microwave combination drying method. They found that the highest effective

Table 1 Effective moisture diffusion activation energy values

Cultivars	Drying conditions	Effective diffusion (m^2/s)	d_{eff} R^2	Activation energy (kJ/mol)	E_a R^2
Viking	360W	4.30×10^{-7}	0.698		
	540W	8.01×10^{-7}	0.806	53.34	0.9542
	720W	2.53×10^{-6}	0.944		
	350W + 50 °C	4.34×10^{-7}	0.979		
	350W + 60 °C	6.47×10^{-7}	0.941	35.87	0.9999
	350W + 70 °C	9.43×10^{-7}	0.944		
Nero	360W	4.00×10^{-7}	0.766		
	540W	7.23×10^{-7}	0.854	45.50	0.8964
	720W	1.89×10^{-6}	0.950		
	350W + 50 °C	5.44×10^{-7}	0.903		
	350W + 60 °C	4.82×10^{-7}	0.871	71.49	0.9759
	350W + 70 °C	6.68×10^{-7}	0.914		

moisture diffusion value determined in drying processes was $6.0768\times10^{-}9m^2s^{-1}$. It is seen that the findings in the literature are lower than the effective moisture diffusion values obtained in this study. This is thought to be due to the different structural forms of the dried products. For MD and MACD drying methods, it was determined that the effective moisture diffusion values increased with increasing drying conditions. A similar situation was reported in the study of Filipović et al. (2022). For both types of aronia puree, it was observed that the effective moisture diffusion values were higher in the MD process than in the MACD process. The reason for this is that the moisture diffusing away from the product is separated from the product faster due to the pressure difference and traveled further than the MACD method. When compared with other microwave and hybrid drying conditions for the Viking cultivar, effective moisture diffusion values in 360 W and 350 W + 50 °C drying processes were found closer. For the Nero cultivar, effective moisture diffusion values in 360 W and 350W + 60 °C drying processes were found closer. It was observed that the effective moisture diffusion values determined at 360 W power values for both cultivars were lower than the values determined for 350 W + 50 °C and 350 W + 60 °C drying conditions. This situation caused the moisture moving away from the product from the oven support to move further in the environment during the MACD drying process. The highest effective moisture diffusion values for the Nero cultivar were determined at 540 and 720 W power values. For the Viking cultivar, although the rate of moisture diffusion (DR) at 540 W power value was determined to be higher than the 350 W + 70 °C drying condition, the effective moisture diffusion value was determined to be lower. The reason for this is thought to be related to the way the moisture diffuses into the environment (flow regime). The moisture removed from the products in the drying condition of 350 W + 70 °C for MACD may have shown a more aerosol flow pattern in the environment than the MD method. This situation caused the effective moisture diffusion values determined for MACD to be higher than the values determined for MD. Activation energy values of the Viking cultivar were determined as 53.34 and 35.87 kJ/mol in MD and MACD methods, respectively. For the Nero cultivar, these values were found to be 45.50 and 71.49 kJ/mol, respectively. Aghbashlo et al. (2008) dried berberis fruits in a convective type dryer at temperatures of 50, 60, and 70 °C. They reported that the activation energy values of the drying processes varied between 110.84–130.61 kJ/mol, respectively. The reason why the values in the literature are higher than the activation energy values determined in this study may be due to the differences in drying methods, device sizes, and fruits used. Motevali et al. (2012) dried jujube fruits in the convective dryer at 50, 60, and 70 °C temperature and 0.5, 1, and 1.5 ms^{-1} air velocity. As a result of the study, they reported that activation energy values varied between 34.97 and 74.20 kJ/mol. It was observed that these values and the values determined within the scope of the study were compatible with each other.

Physicochemical properties

The physicochemical properties of Viking and Nero cultivar *Aronia* powders produced are given in Table 2.

According to Table 2, there was no significant ($p > 0.05$) difference between MD 360 W and MACD.

350 W + 50 °C methods in terms of L value for the Viking cultivar. In the Viking cultivar, higher brightness values ($p < 0.05$) were determined at lower values of microwave power and temperature. This was because darkening remained at a more limited level at low drying conditions. In MD and MACD methods, L values decreased statistically ($p < 0.05$) with increasing values of microwave power and temperature, respectively. For the Nero cultivar, the highest

Table 2 Physicochemical values of Viking and Nero varieties of aronia fruit

Parameters	360W	540W	720W	350W + 50 °C	350W + 60 °C	350W + 70 °C
Viking						
L	32.34 ± 0.20a	22.57 ± 0.67d	21.17 ± 0.35e	32.81 ± 0.11a	29.43 ± 1.49b	23.77 ± 2.24c
a	8.82 ± 0.14e	12.00 ± 0.40c	14.58 ± 0.74a	9.90 ± 0.18d	7.18 ± 0.28f	13.52 ± 1.43b
b	3.40 ± 0.31a	0.30 ± 0.32c	1.93 ± 0.18b	3.13 ± 0.06a	0.28 ± 0.77c	0.32 ± 0.71c
C	9.46 ± 0.18e	12.01 ± 0.41c	14.70 ± 0.74a	10.38 ± 0.19d	7.22 ± 0.30f	13.54 ± 1.45b
CI	50.44a	45.39a	59.66a	43.86a	60.90a	25.47a
HR	0.70b	0.71b	0.64b	0.71b	0.96b	1.36a
Wettability	187.33c	321.33a	169.00d	168.67d	299.67b	164.33d
Nero						
L	32.79 ± 0.11a	18.53 ± 0.62f	28.36 ± 0.47c	22.72 ± 0.40e	31.07 ± 0.64b	23.77 ± 2.24d
a	10.05 ± 0.17bc	6.64 ± 0.27d	9.51 ± 0.76c	10.44 ± 0.42b	12.78 ± 0.96a	13.42 ± 1.56a
b	3.17 ± 0.14a	−0.38 ± 0.43d	−0.87 ± 0.28e	−0.56 ± 0.38d	0.74 ± 0.48b	0.32 ± 0.58c
C	10.53 ± 0.17b	6.65 ± 0.26d	9.55 ± 0.74c	10.46 ± 0.41b	12.80 ± 0.95a	13.44 ± 1.57a
CI	45.11ab	58.17ab	86.11a	61.57ab	32.20b	57.97ab
HR	0.71ab	0.67ab	0.56b	0.64ab	0.77a	0.65ab
Wettability	134.00b	102.67c	111.33c	181.00a	177.00a	90.33c

The a, b, c, d, e indicate the level of difference of the merge

L value ($p < 0.05$) was determined at 360 W power value in the MD method.

Zia and Alibas (2021) dried blueberry fruit in different drying systems. They found that the L value of blueberry fruit decreased under high drying conditions in their drying processes with the hybrid method. It was observed that the findings in the literature and the findings obtained in this study were compatible with each other. The highest value for the Viking cultivar was determined at 720 W power value. The highest for the Nero variety value was determined in the processes performed at 350 W + 60 °C and 350 W + 70 °C drying conditions. In the study conducted by Zia and Alibas (2021) at 300 W + 50 °C, 300 W + 70 °C and 300 W + 90 °C drying conditions, it was determined that the value of blueberry fruit increased with increasing temperature value. When the Viking cultivar was analyzed in terms of b (blueness) value, it was found to be higher in MD 540 W and MACD 350 W + 60 °C and 350 W + 70 °C processes. In the Nero cultivar, the b (blueness) value was found to be higher in the MD 540 W process. In the MD method, both the high drying time and the exposure to high microwave power value are thought to cause caramelization in the puree. In the MACD method, exposure to high drying conditions caused caramelization of the puree and increased blue color pigment intensity. Bustos et al. (2018) dried blackcurrant and blackberry fruits at temperatures of 50, 65, and 130 °C. They found the best color values for both fruits in the drying process at 65 °C. Wojdylo et al. (2009) reported that the best color values of strawberry fruit were determined at 240 W power value compared to 360 and 480 W power values in their study with microwave assisted vacuum dryer. It was observed that the findings in the literature were compatible with the findings obtained in this study. There was no statistically significant difference ($p > 0.05$) between the CI values of fruit powders of Viking cultivar produced by different drying methods. In other words, drying methods had no statistically significant effect on the spillability of Viking cultivar powders. When Viking cultivar fruits were dried at 350 W + 70 °C drying conditions, the CI value of the fruit powder was determined to be in the "weak" category. The CI value of fruit powders produced by methods other than this drying condition was in the "very very poor" category. Ribeiro et al. (2020) reported that the CI values of cocoa powders produced by using maltodextrin agents in different drying methods ranged between 24.88 and 28.17. These values were found to be between "passable" and "poor" levels. It was observed that the values obtained in the literature were compatible with the CI values of the powders produced in MACD 350 W + 70 °C drying condition in this study. The CI values of guava and pitaya fruit powders produced by the freeze drying method by Zea et al. (2013) were determined as 27.20 and 34.90, respectively. It was observed that the CI values determined for guava and pitaya fruit powders were at "poor" and "very poor" levels, respectively. Hadree et al. (2023) reported that the CI values of pomegranate powders produced by the spray drying method varied between 17.80 and 33.40. The CI values determined were reported to be between "fair" and "very poor" levels. It is seen that the CI values determined in this study are compatible with the values in the literature. Except 350 W + 70 °C drying condition, other drying conditions had no effect ($p > 0.05$) on the HR values of the Viking cultivar.

When the fruits of the Viking cultivar were dried at 350 W + 70 °C and converted into powder, it was determined that the HR value was in the "poor" category and the HR value of the powders produced under other drying conditions was in the "excellent" level. When the effect of drying processes on the CI values of the Nero cultivar was analyzed, a statistically significant ($p < 0.05$) difference was found between 720 and 350 W + 60 °C processes. When the fruits of the Nero cultivar were dried at 350 W + 60 °C, the CI value of the fruit powder was in the "very weak" category; while, the CI values of the fruit powders produced by methods other than this drying condition were in the "very very weak" category. When the HR values of the Nero cultivar were analyzed, the difference between 720 and 350 W + 60 °C drying conditions was found to be significant. The HR values of the fruit powders produced in all drying conditions of Nero cultivar fruits were in the "excellent" category. Zea et al. (2013) determined the HR values for guava and pitaya fruit powders as 1.37 and 1.53, respectively, and reported that the HR levels of these values were "poor" and "very poor," respectively. Ribeiro et al. (2020) documented that the HR values of the cocoa powders they produced ranged between 1.33 and 1.39 and the HR levels were "passable" and "poor." Hadree et al. (2023) reported that the HR values of pomegranate powders produced by the spray drying method ranged between 1.20 and 1.50 and these values were in the "fair" and "very poor" levels. It was observed that the findings in the literature were compatible with the findings obtained in this study. It was found that the effect of drying methods on the wettability time of powders of Viking and Nero cultivars was significant ($p < 0.05$). The highest wettability time of the Viking cultivar was determined at a 540 W power value. It is thought that gelation, caramelization, oil accumulation, large particle size, etc. during the drying process affect this situation. These events may have increased the wetting time by preventing the powder particles from soaking in water. Bhandari (2013) reported that increased fat coverage on the surface can result in poor wettability, reduced flowability, and increased oxidation potential. According to Barbosa-Cánovas and Juliano (2005) the presence of free fat on the powder particle surface reduced the wettability of the powder, thus yielding tablets with a low dissolubility. To determine the real reason for this, some analyses such as size distribution, fat, and protein of the produced powders should be performed. Drying methods were found to affect the hygroscopicity values of the produced aronia powders. While hygroscopicity values for the Viking cultivar varied between 69–77%, this rate for the Nero cultivar varied between 71 and 91%. Gagneten et al. (2019) determined the hygroscopicity ratios of raspberry, blackcurrant, and elderberry fruit powders produced by spray drying method as 13.14, 11.80 and 12.74%, respectively. Vidović et al. (2019) reported that the hygroscopiste ratios of aronia powder produced by spray drying varied between 13.10 and 15.0%. Kapoor and Feng (2022) found the highest hygroscopicity rate for cranberry powder produced by different drying systems with 33.55% in the freeze drying method. Within the scope of this study, it was found that the hygroscopicity rates of Viking and Nero cultivars were higher than the rates stated in the literature. This is thought to be due to the microwave and microwave assisted hot air drying methods used in this study.

SMER and SEC values

The distribution of time-dependent SMER and SEC energy consumption values during the drying processes is given in Fig. 2.

According to Fig. 2, drying methods affected the energy consumption values of aronia cultivars. The SMER and SEC values of the drying processes of the Viking cultivar varied between $5.536–15.30 \times 10^{-3}$ kg/kWh and 65.38–180.65kWh/kg, respectively. The SMER and SEC values of the drying processes of the Nero cultivar were found to vary between $6.045–15.95 \times 10^{-3}$ kg/kWh and 62.68–165.43kWh/kg, respectively. Rojas et al. (2020) determined that SEC energy consumption values varied between 82.50 and 150.90kWh/kg in their study with a hot air drying system. It was observed that the findings in the literature were consistent with the findings in this study. (2018) pulverized onions using hot air, freeze drying, and microwave assisted freeze drying methods. The average SEC energy consumption values of the drying processes were determined as $7–9 \times 10^5$ kJ/kg (195–250kWh/kg). The reason why the SEC values in the literature are higher than the findings obtained in this study is that the drying processes were carried out at 45 °C. At low drying temperatures, the product reaches the desired moisture level in a longer time. This increased the amount of energy consumed by the device.

Bioactive properties

Bioactive values of fresh and powdered Viking and Nero cultivar aronia fruits are given in Fig. 3.

As a result of the analyses, it was determined that different drying methods caused significant changes in the bioactive content of the samples. The bioactive substances in the content of aronia fruits became more concentrated and their amounts increased after the powdering process (Yilmaz et al. 2021; Kaya Dursun et al. 2023). The total phenol content of the samples ranged from 9.366 mg GAE g^{-1} fw to 37.667 mg GAE g^{-1} dw in the Viking cultivar and from 10.511 mg GAE g^{-1} fw to 34.067 mg GAE g^{-1} dw in the Nero cultivar (Fig. 3A). The highest total phenol content was determined in Viking cultivar samples at 720W drying conditions. When total flavonoid content was analyzed,

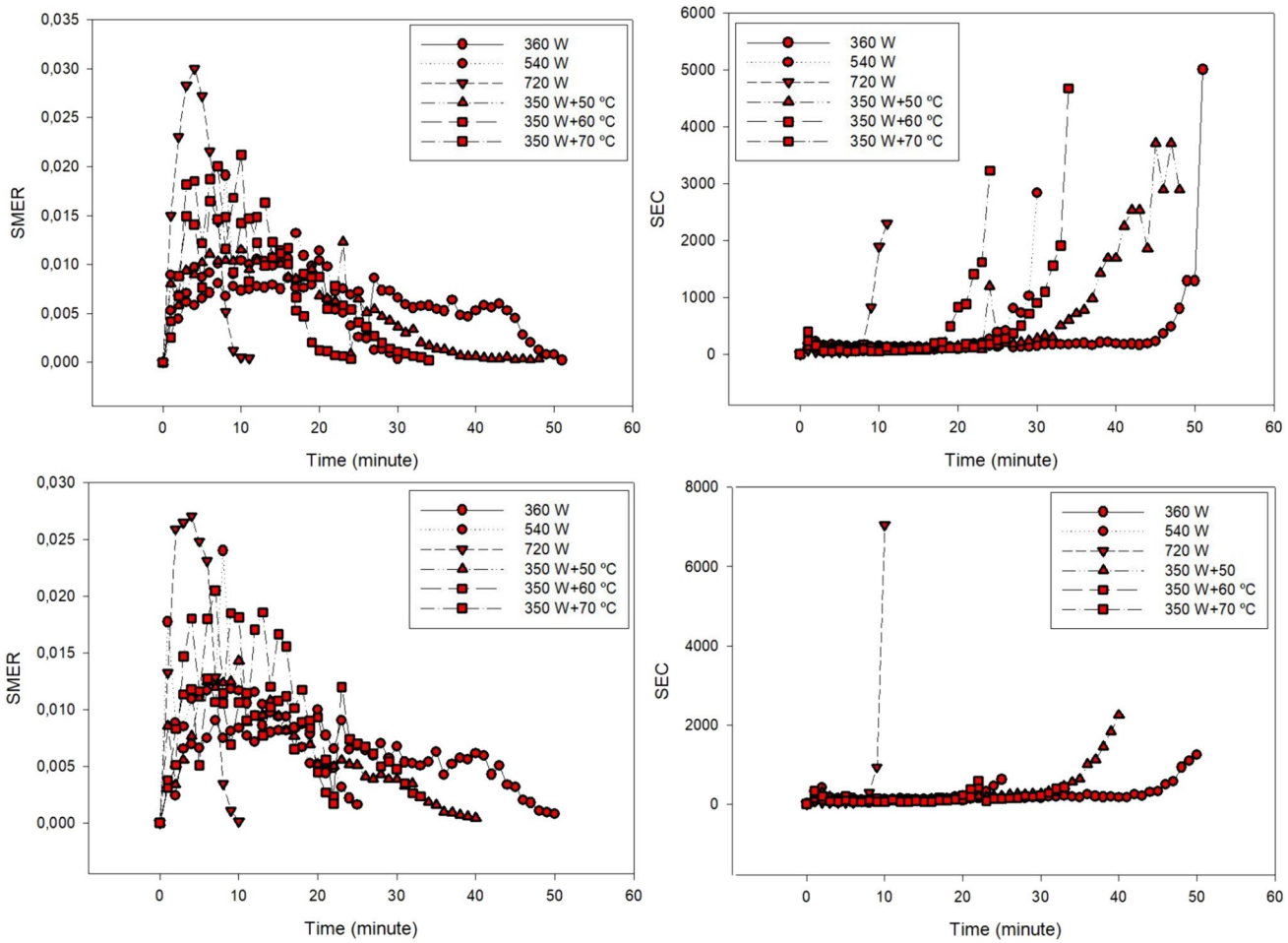


Fig. 2 Energy consumption values **a** MD, **b** MACD

it was determined that Viking cultivar samples had values between 1.522 g CE L^{-1} fw and 18.540 g CE L^{-1} dw, and Nero cultivar samples had values between 1.597 g CE L^{-1} fw and 19.184 g CE L^{-1} dw. The highest flavonoid content was found in Nero cultivar samples at 360 W drying conditions. This was followed by Nero and Viking cultivar samples at 720 W drying condition and Nero cultivar samples dried at 350 W + 70 °C. Total anthocyanin contents varied between 0.712 mg cy-3-gal g^{-1} fw and 4.985 mg cy-3-gal g^{-1} dw in Viking cultivar samples and between 0.663 mg cy-3-gal g^{-1} fw and 3.759 mg cy-3-gal g^{-1} dw in Nero cultivar samples. The highest anthocyanin content was found in Viking samples dried at 350 W + 60 °C. This was followed by Viking and Nero samples dried at 350 W + 50 °C. Finally, when the total antioxidant activity was analyzed, it was found that Viking cultivar samples had values between 6.12 µmol TE g^{-1} fw and 272.41 µmol TE g^{-1} dw, and Nero cultivar samples had values between 5.69µ mol TE g^{-1} fw and 265.38µ mol TE g^{-1} dw. The highest antioxidant activity was detected in Viking samples at 540 W drying condition and this was followed by Nero samples dried at the same condition. MD and MACD drying methods had significant effects on the bioactive content of aronia samples. MD drying method had a positive effect on total phenols, flavonoids, and antioxidant activity. MACD drying method had a positive effect on anthocyanin content, especially at 50 and 60 °C temperatures. However, Viking and Nero cultivars showed different responses to the drying processes applied. This situation shows us how much difference can be even between two cultivars. In terms of enterprises, the optimum drying method should be determined separately for each cultivar to be converted into powder.

Conclusion

When agricultural products and wastes are dried and turned into powder, their added value increases. In this study, aronia fruits of the Viking and Nero varieties were dried in microwave and hybrid drying systems and turned into powder. It

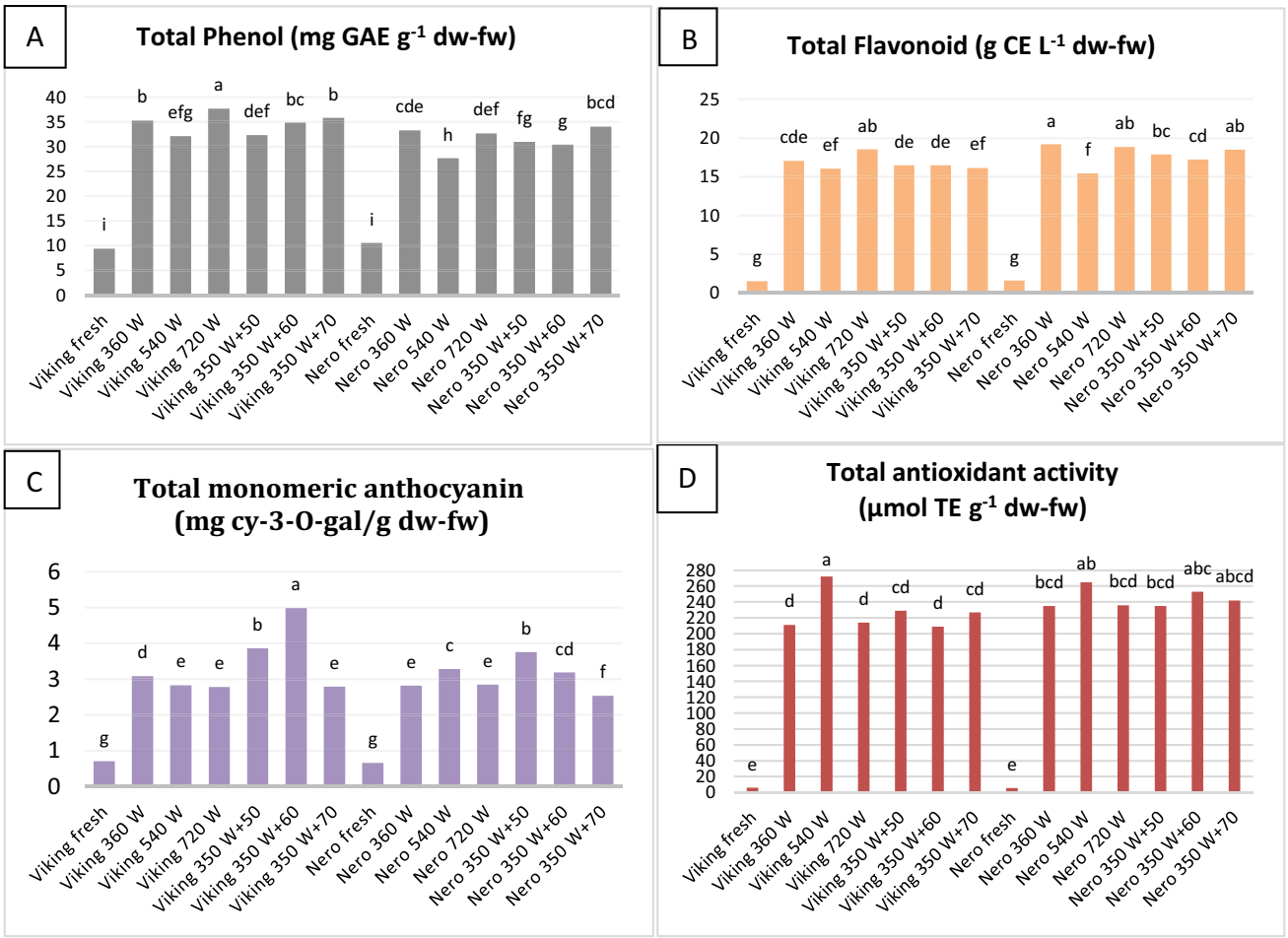


Fig. 3 Bioactive values

has been observed that drying methods significantly affect the drying kinetics, energy consumption, physicochemical, and biochemical properties of aronia powders. The microwave drying method affected the physicochemical properties of aronia varieties more negatively than the hybrid drying method. Among the drying processes, the shortest drying time was 10 min in the 720 W drying process of the Nero variety. However, the highest drying rate and effective moisture diffusion value were determined in the 720 W drying process of the Nero variety with 3.04×10^{-1} g moisture/g dry matter min and in the 720 W drying process of the Viking variety with $2.53 \times 10^{-6} m^2 s^{-1}$, respectively. The microwave assisted convective drying method had a better effect on the Carr values (25.47) of aronia powders. It was determined that the Nero variety was more advantageous than the Viking variety in terms of SMER and SEC values. The SMER and SEC values for the Nero variety ranged between $6.045–15.95 \times 10^{-3}$ kg/kWh and 62.68–165.43kWh/kg, respectively. It was determined that the effective moisture diffusion values of the Viking variety in the drying process were higher than the Nero variety. It was determined that the effective moisture diffusion value of the Viking variety varied between 4.30×10^{-7} and $2.53 \times 10^{-6} m^2 s^{-1}$. When evaluated in terms of bioactive properties, it was seen that the Viking variety was better than the Nero variety. The total phenol, monomeric anthocyanin, and antioxidant contents of the Viking variety range from 9.366 mg GAE g^{-1} fw to 37.667 mg GAE g^{-1} dw, 0.712 mg g^{-1} fw to 4.985 mg g^{-1} dw, 6.12µ mol TE g^{-1} fw, respectively, has been found to change. It was determined that the microwave drying method, especially at 50 °C and 60 °C temperatures, had a more positive effect on total phenol, flavonoid, and antioxidant activity, and the hybrid drying method had a more positive effect on the anthocyanin content.

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Author contributions Muhammed Taşova contributed to planning, data processing, and article writing. Muhammed Rahmetullah Çiğdem contributed to laboratory work, data processing, and article writing. Samet Kaya Dursun contributed to laboratory work and data processing. Onur Saraçoğlu contributed to planning and editing.

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Data availability All the data used in the manuscript are available in the tables and figures.

Declarations

Conflict of interest The author in the study has no conflict of interest with any other author.

Ethical approval This study has been prepared in accordance with ethical standards.

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