Croatian Journal of Food Science and Technology

w w w . p t f o s . u n i o s . h r / c j f s t /

since 2009

Enhancing nutraceutical integrity in functional soft candies through anthocyanin-rich fruits and low-calorie sweetener blend interaction

Aylin Kırbaş Kesen[1], Muhammed Ali Doğan[2], Aygül Can[3], Çiğdem Uysal Pala[2*]

[1]Çanakkale Provincial Directorate of Youth Services and Sports, 17100 Çanakkale, Türkiye
[2]Çanakkale Onsekiz Mart University, Faculty of Engineering, Department of Food Engineering, 17100 Çanakkale, Türkiye
[3]Gaziantep Islam, Science and Technology University, Faculty of Architecture, Design and Fine Arts, Department of Gastronomy and Culinary Arts, 27000 Gaziantep, Türkiye

ARTICLE INFO

TYPE: Original scientific paper
https://doi.org/10.17508/CJFST.2026.18.1.01

*CORRESPONDENCE
Çiğdem Uysal Pala
✉ cigdemuysal@comu.edu.tr

ARTICLE HISTORY
Received: October 15, 2025
Accepted: November 27, 2025

CITATION
Kırbaş Kesen A, Doğan MA, Can A, Uysal Pala Ç. Enhancing nutraceutical integrity in functional soft candies through anthocyanin-rich fruits and low-calorie sweetener blend interaction. Croatian Journal of Food Science and Technology (2026) 18 (1) 1—17

KEYWORDS
functional confectionery; aronia; low-calorie sweetener; storage stability; anthocyanin; antioxidant properties

KEY CONTRIBUTION

Aronia puree significantly increased anthocyanin and phenolic content, enhancing antioxidant activity. Sucrose-based soft candies exhibited higher anthocyanin content than low-calorie alternatives. At 20 °C, aronia-based low-calorie candies retained anthocyanins better than sucrose-based versions. Cold storage preserved anthocyanin content and antioxidant activity more effectively than storage at 20 °C.

ABSTRACT

This study developed nutraceutical soft candies enriched with anthocyanins from pomegranate and aronia, utilising both sucrose and a low-calorie sweetener system (erythritol and sucralose). The impact of fruit source, sweetener type, and storage temperature (4 °C and 20 °C for 90 days) on anthocyanin stability and antioxidant properties was investigated. Incorporation of aronia puree significantly increased total monomeric anthocyanin content (TMAC) to 74.01 mg C3G/100 g (sucrose-based, APS) and 67.88 mg C3G/100 g (low-calorie, APE), compared to pomegranate-only formulations (15.25 mg C3G/100 g and 11.49 mg C3G/100 g in PJS and PJE, respectively ($p<0.05$). This trend also applied to total phenolic content (TPC) and antioxidant properties. The choice of sweetener strongly influenced anthocyanin stability, with the low-calorie erythritol-sucralose blend providing significant protection. Kinetic analysis revealed longer half-lives ($t_{1/2}$, 85.99 days for APE and 52.80 days for APS at 4 °C). At 20 °C, low-calorie APE retained significantly higher TMAC ($p<0.05$). Antioxidant retention was primarily temperature-dependent, but it was enhanced by the low-calorie sweetener, especially in aronia puree-based candies, while the total phenolic content (TPC) remained relatively stable. These findings demonstrate that aronia puree and low-calorie sweeteners can synergistically enhance the nutraceutical quality of these functional confectionery products during storage.

Introduction

The growing interest in health-conscious diets has led to increasing demand for functional foods that satisfy cravings while providing nutritional benefits. Confectionery products, particularly soft candies, present a valuable opportunity for nutraceutical enrichment. The incorporation of natural pigments into soft candy formulations not only enhances their visual appeal but also contributes to their functional properties through the addition of bioactive compounds, making them desirable to health-conscious consumers (Cano-Lamadrid et al., 2020). Soft candies enriched with natural pigments such as anthocyanins and other bioactive phenolics represent a promising alternative to conventional sucrose-based products. Anthocyanins, a subclass of water-soluble flavonoids responsible for the red, purple, and blue pigmentation in many fruits, are widely recognised for their antioxidant capacity and potential health-promoting effects, including anti-inflammatory, anti-carcinogenic, and cardioprotective activities (Ayvaz et al., 2022; Li et al., 2025). Recent evidence also highlights their role in modulating gut microbiota, further underscoring their functional significance in preventive nutrition (Groh et al., 2020; Kapoor et al., 2023). Fruits such as pomegranate and aronia are exceptionally rich sources of anthocyanins. However, the reformulation of soft candies is technically challenging, as interactions between fruit bioactives, gelling agents, and sweeteners are complex and can significantly alter the stability and bioavailability of key nutraceutical compounds as anthocyanins (da Silva et al., 2016; Zhou et al., 2018; Salar et al., 2022). The addition of fruit in pulp and juice form can significantly enhance the nutraceutical profile of soft candies by introducing prebiotic constituents such as pectin and antioxidant phenolics (Ali et al., 2021; da Silva et al., 2016), which are often absent in conventional candy products. Concurrently, the use of low-calorie sweeteners, such as erythritol and sucralose offers a strategy to reduce caloric content while maintaining desirable taste and texture (Efe and Dawson, 2022; Riedel et al., 2015). A critical challenge in developing such functional confectionery is ensuring the stability of bioactive compounds, particularly anthocyanins, which are highly sensitive to processing and storage conditions. Factors such as temperature, pH, and the presence of other matrix components can lead to substantial degradation through oxidative or hydrolytic reactions, ultimately diminishing both the health benefits and visual quality of the products (Kaloudi et al., 2022; Türkyılmaz et al., 2025). Previous research on fruit-based products such as juices and jams, has demonstrated that both processing methods and storage conditions markedly alter anthocyanin content and antioxidant activity (Lv et al., 2024; Nowicka and Wojdyło, 2016; Scrob et al., 2022a). The intrinsic complexity of these polyphenolic matrices means that interactions with other ingredients can either stabilise anthocyanins through co-pigmentation or accelerate their degradation, underscoring the importance of evaluating both anthocyanin content and antioxidant capacity over time (Salman et al., 2025). Therefore, the aim of this study was to identify optimal strategies for enhancing nutraceutical integrity- specifically anthocyanin retention and antioxidant properties-in soft candies as functional confectionery products. This was achieved by elucidating the interactions among fruit source (pomegranate concentrate and juice, and aronia puree), sweetener type (sucrose and erythritol + sucralose), and storage temperature (4 °C and 20 °C). In this regard, four different soft candy formulations were evaluated, enabling the development of low-calorie soft candies enriched with phenolic bioactives, particularly anthocyanins, which serve as natural colourants and potent antioxidants.

Materials and methods

Plant material, chemicals, and reagents

Pomegranate concentrate (cv. Hicaz) was obtained from Dimes Fruit Juice Factory (Turkey), and fresh pomegranates (cv. Hicaz) were sourced from a local vendor in Çanakkale. Organic aronia berries (cv.

Nero) were provided by a producer in Yalova (Producer No: M-77-26). Stevia and sucralose were supplied by Egepak (Turkey); gelatin (250 Bloom) by Benosen (Turkey); and erythritol and high acyl gellan gum by Arısan (Turkey). Folin–Ciocalteu reagent, gallic acid, neocuproine, DPPH, and Trolox were purchased from Sigma-Aldrich (Germany).

Pomegranate concentrate-based soft candy production

The soft candy formulations containing two anthocyanin sources and two sugar alternatives were prepared (Table 1). First, gelatin and gellan gum were dissolved in pomegranate juice (extracted using a juicer) or aronia puree (diluted 1:1 w/v with water and strained through cheesecloth). The gelatin mixture was then added to a blend of pomegranate concentrate and sweeteners (erythritol with sucralose or sucrose), to form a preliminary syrup. This syrup was cooked at 75 °C for 10 minutes with constant stirring. The mixture was then poured into moulds to complete the gelation process and left to set at 4 °C for 48 hours. After production, the physicochemical and nutraceutical properties of soft candies were analysed.

Physicochemical properties of soft candies

Total Solids (TS), pH, and Titration Acidity (TA): Soft candies were dried at 70–80 °C to constant weight, and TS content was calculated based on weight loss. The pH of the aqueous soft candy extract (1:5, w/w) was measured at room temperature using a pH meter (Seven Compact S210, Mettler Toledo, US). TA was determined by potentiometric titration with 0.1 N NaOH, using the pH meter to monitor the endpoint at pH 8.1, and the results were expressed as % anhydrous citric acid (AOAC Official Method 935,29 for TS, 943.02 for pH and 942.15 for TA; AOAC, 2000).

Colour: *L** (lightness), *a** (red/green), and *b** (yellow/blue) parameters as colour values of the soft candy samples were measured using a colourimeter (Minolta CR-400, Konica Minolta Sensing Inc., Japan) based on the CIE colour system recording.

Bioactive compounds and antioxidant activity of soft candies

Total monomeric¸anthocyanins content (TMAC): The pH differential method was used to determine TMAC (Giusti and Wrolstad, 2001). An aqueous soft candy extract was diluted with buffer solutions at pH 1.0 and pH 4.5, respectively. After a 30-minute incubation at room temperature (RT), the absorbance difference (A) was calculated based on measurements at 520 nm and 700 nm. TMAC was determined using Equation 1 and expressed as mg cyanidin-3-glucoside (C3G) per 100 g of soft candy.

$$TMAC\ (mg\ C3G\ /\ 100\ g) = \frac{(A)(MW)(DF) \cdot 100}{(\varepsilon)(1)} \tag{1}$$

Where:

A = $(A520nm - A700nm)_{pH1.0} - (A520nm - A700nm)_{pH4.5}$

MW = Molecular weight of C3G (449.2 g/mol)

DF = Dilution factor

ε = Molar extinction coefficient for cyanidin-3-glucoside (26,900 L/mol cm)

Total phenolic content (TPC): Ethanolic extracts (1:10, w/v, in 80% ethanol containing 0.01% HCl) were prepared from the soft candy samples. Ethanolic extracts were mixed with Folin–Ciocalteu reagent and sodium carbonate solution, respectively, then incubated at room temperature for 2 hours in the dark.

The absorbance was subsequently measured at 765 nm. TPC values were calculated using a gallic acid calibration curve and expressed as mg gallic acid equivalent (GAE) per 100 g of soft candy (Singleton and Rossi, 1965). CUPRAC: Ethanolic extracts were mixed with copper (II) chloride, neocuproine, and ammonium acetate, respectively. After a 30-minute incubation under dark room conditions, the absorbance was measured at 450 nm. Results are expressed as mg Trolox/100 g of soft candy (Apak et al., 2004). *DPPH:* Ethanolic extracts (20–100 µL) were mixed with DPPH solution. After 15 minutes of incubation in the dark at room temperature, the absorbance was measured at 517 nm. Results were expressed as IC_{50} (mg), representing the sample amount required to inhibit 50% of the DPPH radical activity (Benvenuti et al., 2004).

Temperature-dependent storage and anthocyanin degradation kinetics

Following production, the moulds containing the soft candies were sealed to ensure airtight and moisture-proof conditions, and then stored in the dark at 4 °C and 20 °C for 90 days. Sampling was performed monthly to assess the nutraceutical properties (TMAC, TPC, CUPRAC, and DPPH) of the soft candies throughout the storage period. The degradation of anthocyanins in the soft candy formulations during 60 days of storage at4 °C and 20 °C was evaluated using a first-order kinetic model (Patras et al., 2010). This model (Eq. 2) describes the decrease in monomeric anthocyanin concentration over time, where C_o is the initial concentration, C is the concentration at time t, and k is the rate constant. The k values were obtained from the slopes of the regression lines derived from the logarithmic changes in anthocyanin content over time at each storage temperature. The rate constants were calculated by multiplying the slope by 2.303 (Eq. 3). The half-life $t_{(1/2)}$ of anthocyanin degradation was also determined based on the rate constant (Eq. 4).

$$\ln\left(\frac{C}{Co}\right) = -kx \tag{2}$$

$$k = slope \times 2{,}303 \tag{3}$$

$$t_{1/2} = ln(0{,}5) \tag{4}$$

Sensory analysis

The sensory properties (flavour, appearance, and overall acceptability) of the pomegranate-based samples (concentrate + juice) were assessed by 66 panellists using a 7-point hedonic scale (1: dislike very much, 7: like very much) (Meilgaard et al., 1999). All participants were fully informed about the purpose of the study and provided written consent before participation. No personal identifying information was collected, ensuring confidentiality.

Statistical analysis

All experiments were conducted in triplicate, and the results were expressed as mean ± standard error (SE). The data were analysed using analysis of variance (ANOVA), and significant differences between means ($p<0.05$) were determined using Tukey's test. A full factorial design was applied for statistical evaluation using JMP® Pro software (version 18.0.2, JMP Statistical Discovery LLC, Cary, NC, US).

Results and discussion

Developing low-calorie soft candy formulations using pomegranate concentrate and juice

Control group: A preliminary evaluation was conducted to determine the sucrose-containing control group. Twelve formulations (n=12) with varying proportions of pomegranate concentrate (25-50%), pomegranate juice (18-40%), sucrose (17-45%), and gelatin (5-15%) were tested (data not shown). In selecting the optimum formulation for the control group, key objectives were identified for the subsequent stage: achieving at least a 30% reduction in caloric value, maximising anthocyanin content, ensuring a balanced sugar-to-acid ratio, and maintaining adequate gelatin solubility during production. Based on these criteria, the control formulation was defined as pomegranate juice-based soft candies with sucrose (PJS), consisting of 24.0% pomegranate concentrate, 38.0% pomegranate juice, 28.5% sucrose, and + 9.5% gelatin.

Erythritol concentration: Erythritol is a naturally occurring sugar alcohol (polyol) present in various fruits, providing about 60–70% of the sweetness of sucrose. It delivers a mild cooling sensation without any aftertaste and contributes negligible caloric value (Mazi and Stanhope, 2023). To match the sweetness level provided by sucrose in PJS formulation, an equivalent sweetness intensity was achieved by substituting sucrose with a polyol (erythritol) in combination with sucralose and/or stevia. One of the major challenges in developing low-calorie formulations is the risk of crystallisation associated with high erythritol concentrations. Erythritol exhibits moderate water solubility (~37% w/w at 25 °C) and very low hygroscopicity, both significantly lower than those of sucrose (~67% w/w at 25 °C) (Perko and DeCock, 2006). Based on this, soft candy formulations containing different concentrations of erythritol (20-40%) were tested and evaluated for crystallisation (Fig. 1). Crystallisation onset was observed at erythritol concentrations of 30% and above. Therefore, to avoid potential crystallisation problems during storage and consumption, the erythritol concentration was limited to 20% in the final low-calorie formulations.

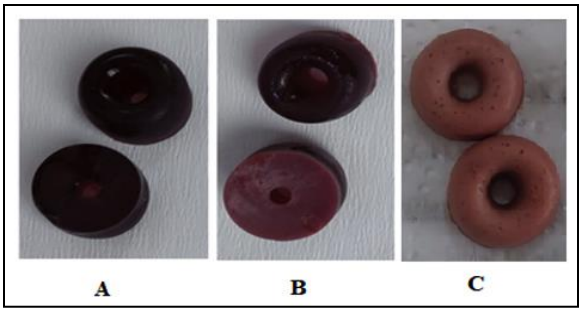

Figure 1. Soft candy formulations containing different concentrations of erythritol: (A) 20% erythritol; (B) 30% erythritol; (C) 40% erythritol

Low-calorie formulations: Accordingly, sucrose-equivalent sweetness was achieved using erythritol in combination with sucralose and/or stevia. Subsequently, PJS was used as the base formulation, and three different low-calorie formulations were developed using these sweeteners either alone or in a 1:1 (w/w) combination: pomegranate juice-based soft candies with erythritol PJE), stevia, PJE: stevia + sucralose, and PJE: sucralose. The sensory acceptability of the low-calorie formulations, as well as the control group (PJS) is given in Table 2. No significant differences (p>0.05) were observed among PJE: stevia + sucralose, PJE: sucralose, and the control (PJS) in terms of flavour, appearance, and overall acceptability. The overall acceptability scores of the two low-calorie formulations remained within the 5–6 range, indicating that panellists found them pleasant and acceptable. Furthermore, in terms of preference, PJE: sucralose was the most favoured formulation, chosen by 52% of the panellists, followed by PJE: stevia + sucralose with 44% (data not shown). Among the low-calorie formulations, PJE: stevia was the least preferred in terms of all sensory properties (p<0.05). Although stevia is a widely used natural sweetener, its application as a primary sugar substitute is often limited by its characteristic bitter aftertaste (Lemus-Mondaca et al., 2012; Moazzem et al., 2025). These sensory challenges may have contributed to the comparatively lower acceptance of the PJE: stevia formulation observed in the study. Based on these findings, PJS was selected as the control group formulation and PJE: sucralose, was chosen as the low-calorie alternative for further formulations incorporating aronia puree as an alternative anthocyanin source (Table 1).

Table 1. Formulation of pomegranate concentrate-based soft candies (%, w/w)

Formulation	PJS	APS	PJE	APE
Pomegranate Concentrate	23.72	23.72	26.20	26.20
Pomegranate Juice	38.00	-	41.91	-
Aronia Puree	-	38.00	-	41.91
Sucrose	28.46	28.46	-	-
Erythritol	-	-	20.95	20.95
Sucralose	-	-	0.03	0.03
Gelatin	9.49	9.49	10.48	10.48
Gellan Gum	0.38	0.38	0.42	0.42

PJS: Pomegranate juice–based soft candies with sucrose; PJE: Pomegranate juice–based soft candies with erythritol; APS: Aronia puree–based soft candies with sucrose; APE: Aronia puree–based soft candies with erythritol.

Table 2. Sensory acceptability of the control and low-calorie formulations (mean±SE)

Formulation	Flavor	Appearance	Overall Acceptability
PJE: Stevia	4.20±0.19^{a*}	3.73±0.21^{a}	4.17±0.17^{a}
PJE: Stevia+Sucralose	5.12±0.19^{b}	5.93±0.21^{b}	5.37±0.17^{b}
PJE: Sucralose	5.06±0.19^{b}	5.93±0.21^{b}	5.47±0.17^{b}
PJS (Control)	5.21±0.20^{b}	5.75±0.22^{b}	4.93±0.18^{b}

*Different superscript letters (a,b) within the same column indicate significant differences (p<0.05). PJS: Pomegranate juice–based soft candies with sucrose; PJE: Pomegranate juice–based soft candies with erythritol; APS: Aronia puree–based soft candies with sucrose; APE: Aronia puree–based soft candies with erythritol.

Physicochemical and nutraceutical quality of soft candies

The physicochemical and nutraceutical characteristics of soft candies containing pomegranate concentrate, pomegranate juice, and/or aronia puree are summarised in Table 3.

Table 3. Physicochemical and nutraceutical properties of soft candies (mean±SE)

Parameter	PJS	APS	PJE	APE	±SE
TS (%)	72.65^{a}	72.27^{a}	69.23^{a}	69.02^{a}	1.27
pH	3.69^{a*}	3.87^{b}	3.71^{a}	3.84^{b}	0.01
TA (%)	2.96^{a}	2.07^{b}	3.41^{c}	2.22^{b}	0.03
L* (lightness)	25.77^{a}	24.00^{a}	30.30^{b}	30.12^{b}	0.80
a* (red/green)	5.96^{a}	7.02^{a}	7.68^{a}	8.57^{a}	0.95
b* (yellow/blue)	-9.50^{a}	-10.49^{a}	-5.68^{b}	-4.73^{b}	0.56
TMAC (mg C3G /100 g)	15.25^{c}	74.01^{a}	11.49^{d}	67.88^{b}	0.98
TPC (mg GAE/100 g)	160.71^{b}	235.19^{a}	143.89^{b}	148.28^{b}	13.98
CUPRAC (mg Trolox/100 g)	541.43^{b}	875.28^{a}	596.59^{b}	818.12^{a}	30.42
DPPH (IC_{50}, mg)	9.72^{b}	7.70^{a}	9.28^{b}	7.40^{a}	0.22

*Different superscript letters (a,b,c,d) within the same row indicate significant differences (p<0.05). PJS: Pomegranate juice–based soft candies with sucrose; PJE: Pomegranate juice–based soft candies with erythritol; APS: Aronia puree–based soft candies with sucrose; APE: Aronia puree–based soft candies with erythritol.

The TS content was consistent across all formulations, ranging from 69.02% to 72.65% ($p>0.05$), indicating uniform moisture levels – an important factor for texture and shelf stability. These values align with the typical dry matter contents of gelatin-based jelly candies (Mutlu et al., 2018). The pH values of the soft candies, ranging from 3.69 to 3.87, reflected the natural acidity of the fruit ingredients, classifying them as high-acid foods, which enhances microbial safety. A significantly more pronounced acidic profile was observed in the pomegranate juice-based soft candies (PJS, PJE), which exhibited lower pH and higher TA values compared to the aronia puree-based soft candies formulated with sucrose (APS) and with erythritol (APE) ($p<0.05$). This inherent acidity is particularly beneficial, as it not only supports product safety but also falls within the optimal pH range (3.35–4.36), necessary for achieving desirable gelling properties in fruit-based soft candies (Pratiwi et al., 2023; Renaldi et al., 2022; Székelyhidi et al., 2024).

Sweetener types significantly influenced the colour values of the soft candies (Table 3). Low-calorie formulations (PJE, APE), sweetened with erythritol-sucralose, exhibited significantly higher lightness (L^* values) than their sucrose-based counterparts (PJS, APS). While the red-green coordinate (a^*) remained consistent across samples, sucrose-containing candies displayed more negative b^*values, indicating a greater shift toward blue hues. These colour differences originate from the fruit-derived anthocyanins responsible for the characteristic red-purple pigmentation (Pala and Toklucu, 2011). However, the final colour is also a product of complex matrix interactions; anthocyanin stability is influenced by factors such as pH and the presence of macromolecules like gelatin (Ayvaz et al., 2022), while intermediates from Maillard reactions can lead to pigment degradation (Konar et al., 2025). The observed difference in L^* is likely due to the Maillard reaction. During heating, sucrose can hydrolyse into reducing sugars that react with amino acids in gelatin, promoting non-enzymatic browning and darkening. In contrast, erythritol, a non-reducing sugar alcohol, does not participate in this reaction, resulting in a lighter, less browned final product (Grembecka, 2015).

Aronia puree-based soft candies (APS and APE) exhibited significantly higher TMAC values (67.88-74.01 mg C3G/100 g), compared to those formulated with pomegranate juice (PJS and PJE), which contained 11.59-15.25 mg C3G/100 g ($p<0.05$, Table 3). These results highlight the superior anthocyanin content of aronia and its major contribution to the TMAC of the final products. For comparison, reported TMAC values of pomegranate juice (cv. Hicaz) include 42.6 mg C3G/100 mL (Pala and Toklucu, 2011) and 19.8 mg C3G/100 mL (Türkyılmaz et al., 2025). In contrast, aronia exhibits substantially higher TMAC values, ranging from 426.93 to 794.63 mg C3G/100 g (cv. Nero) and 418.78 to 597.41 mg C3G/100 g (cv. Viking) (Boyaci et al., 2023), as well as 366.54 ± 15.32 mg C3G/100 mL (Nour, 2022) and 73.633 mg C3G/100 mL (Lv et al., 2024). The higher TMAC in aronia puree-based soft candies may also be attributed to the processing method. The soft candies were prepared at ~70 °C, which may have enhanced anthocyanin release from aronia puree prepared with the peel. The peel itself contains about ~73% of the fruit's total anthocyanins (Kaloudi et al., 2022). Moderate heating (60–80 °C) has been shown to improve anthocyanin extraction by increasing diffusion and mass transfer of these water-soluble compounds (Denev et al., 2018). In addition to fruit source and processing conditions, the type of sweetener significantly influenced TMAC. Low-calorie formulations showed markedly lower TMAC values than their sucrose-containing counterparts ($p<0.05$), suggesting that sucrose may provide better protection for anthocyanins during thermal processing. Zhou et al. (2018) reported that adding 5–20% sucrose reduced anthocyanin loss during heating (70–120 °C, 10 min), while Salar et al. (2022) found that sucrose helped preserve anthocyanins and flavanones during storage, whereas sucralose increased flavanone degradation.

TPC varied notably among the soft candies, ranging from 143.89 to 235.19 mg GAE/100 g. The highest TPC was observed in APS (235.19 mg GAE/100 g), which also exhibited elevated TMAC (74.01 mg C3G/100 g) ($p<0.05$). In contrast, PJE and APE displayed lower TPC values (143.89 and 148.28 mg GAE/100 g, respectively), while PJS remained at an intermediate level (160.71 mg GAE/100 g). These findings suggest that the inclusion of aronia puree (APS, APE) substantially contributed to the overall phenolic content compared with their pomegranate-only formulations (PJS, PJE). The pattern is consistent with earlier reports indicating that aronia possesses significantly higher TPC values than pomegranate juices. For instance, the TPC of pomegranate juice has been reported as 174.2 mg GAE/100 mL for cv. Hicaz, 401.0 ± 0.83 mg GAE/100 mL for cv. Hicaz (Pala and Toklucu, 2011). By contrast, the TPC of aronia juice has been reported to have higher values of 678.04 ± 30.42 mg GAE/100 mL (Nour, 2022) and 428.51 mg GAE/100 mL (Lv et al., 2024). Using sucrose as the sweetener, the aronia puree-based soft candies showed higher TPC than the pomegranate-based ones ($p<0.05$). No significant difference was observed between the low-calorie formulations ($p>0.05$), although all exhibited lower TPC than their sucrose counterparts, with a marked reduction in the aronia sample ($p<0.05$). Since the Folin–Ciocalteu method is not fully specific to phenolics, reducing sugars may have contributed to elevated values (Romulo, 2020).

The antioxidant activity of soft candies was evaluated using two complementary methods, CUPRAC and DPPH (Table 3), providing a more comprehensive assessment by capturing different mechanisms and antioxidant types present in complex food matrices (Sethi et al., 2020). The results indicated that the incorporation of aronia puree significantly enhanced the antioxidant capacity of the soft candies ($p<0.05$), whereas the type of sweetener did not produce significant differences. It is worth noting that each analytical method has its own limitations, and results obtained from different assays are not always directly comparable (Sethi et al., 2020). Nevertheless, the CUPRAC and DPPH values demonstrated a parallel trend, supporting the consistency of the findings. Cano-Lamadrid et al. (2020) reported that the TPC of gelatin-based gummies prepared with pomegranate juice or a pomegranate juice/apple puree blend ranged from 72.0 to 159.0 mg GAE/100 g, while the DPPH values varied between 10.6 and 14.9 mg/100 g, indicating a positive correlation between TPC and antioxidant activity. Together, these findings underscore the importance of both raw material selection and sweetener type in determining the stability, bioactive content, and antioxidant activity of soft candies.

Effects of storage on the nutraceutical properties of soft candies

The effect of storage at 4° C and 20 °C for 90 days on the physicochemical and nutraceutical properties of the soft candies was evaluated using TMAC (Fig. 2), TPC (Fig. 3), CUPRAC (Fig. 4), and DPPH (Fig. 5) measurements.

TMAC values decreased in all samples as storage time progressed ($p<0.05$, Fig. 2). At 4 °C, pomegranate juice-based soft candies, particularly PJE, exhibited only minor, non-significant changes in TMAC ($p>0.05$), whereas PJS exhibited a significant reduction by day 90 ($p<0.05$) with a loss of ~31%. In contrast aronia puree-based candies showed substantial reductions, with losses of ~57% for APS and ~42% for APE by day 90 ($p<0.05$). In contrast, storage at 20 °C resulted in a marked decline in TMAC across all formulations, with losses ranging from 64% to 79% during the storage period ($p<0.05$). Although not significant for pomegranate juice-based soft candies, the use of erythritol + sucralose instead of sucrose helped preserve TMAC in aronia puree-based soft candies ($p<0.05$). Similarly, Casas-Forero et al. (2022) reported that storage at 4 °C for 35 days provided better protection of TMAC compared to 20°C, while a total decrease of ~77% was observed in blueberry juice-based soft candies stored at 25°C (Casas-Forero et al., 2022). TMACs are very sensitive compounds, with their stability affected by factors such as pH, temperature, oxygen, light, concentration, and the presence of co-pigments, metal ions, or enzymes. Due to this, temperature significantly accelerates anthocyanin degradation, resulting in polymer formation (Lao and Giusti, 2017).

The degradation of TMAC during storage followed first-order kinetics (Table 4). Both storage temperature and the type of soft candy significantly influenced anthocyanin stability. In all samples, the degradation constant (–*k*) increased markedly as the temperature rose from 4 °C to 20 °C, resulting in a pronounced reduction in half-life. PJS displayed the lowest –*k* value (3.69 at 4 °C), with a half-life of 188.11 days; however, its stability declined sharply at 20 °C ($t_1/_2$: 43.62 days), accompanied by a reduced model fit (R^2=0.59), suggesting less reliable first-order behaviour under elevated temperature. In contrast, APS and APE exhibited faster degradation but maintained consistent first-order kinetics across both storage conditions, with good model fits (R^2>0.90).

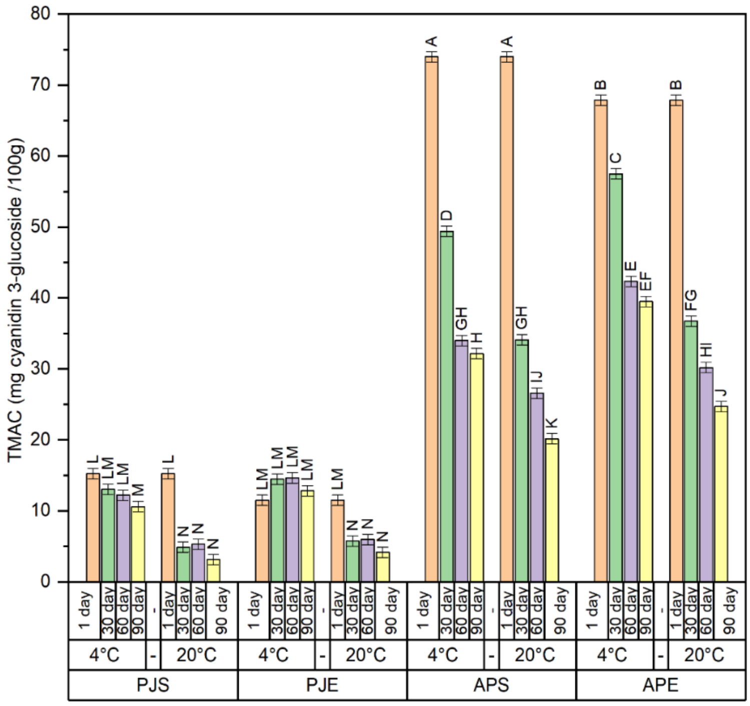

Figure 2. Changes in TMAC values of soft candies during 90 days of storage at 4°C and 20°C. Different letters (A, B) indicate significant differences between samples (p<0.05). PJS: Pomegranate juice–based soft candies with sucrose; PJE: Pomegranate juice–based soft candies with erythritol; APS: Aronia puree–based soft candies with sucrose; APE: Aronia puree–based soft candies with erythritol

Table 4. The first-order kinetic parameters (T: Temperature; *k:* the rate constant; $t_{1/2}$: the half-time; R^2: coefficient of determination) of TMAC of soft candies stored at different temperatures

Formulation	T (ºC)	$-k\times10^3$ (day^{-1})	$t_{1/2}$ (day)	R^2
PJS	4	3.69	188.11	0.94
	20	15.89	43.62	0.59
APS	4	13.13	52.80	0.99
	20	17.27	40.13	0.91
APE	4	8.06	85.99	0.98
	20	13.82	50.16	0.92

PJS: Pomegranate juice–based soft candies with sucrose; APS: Aronia puree–based soft candies with sucrose; APE: Aronia puree–based soft candies with erythritol.

Comparison of APS and APE indicated that the incorporation of erythritol + sucralose lowered –*k* values at both temperatures, extended half-lives, and thereby provided a protective effect on anthocyanins during storage. Likewise, the storage of blueberry juice–based soft candies followed a first-order kinetic model, and storage temperature significantly affected the degradation of their bioactive compounds (Casas-Forero et al., 2022). Scrob et al. (2022a) examined the kinetics of anthocyanins degradation in lingonberry (*Vaccinium vitis-idaea* L.) jam formulated with various sweeteners (sucrose, fructose, erythritol, brown sugar, coconut sugar, stevia, saccharin) and stored at 4 °C and 25 °C for 180 days. Similarly, anthocyanin degradation followed first-order kinetics with high model reliability (R^2>0.96). Although anthocyanins were generally better preserved in jams stored at 4 °C, significant losses were observed after 60 days. Additionally, the type of sweetener also strongly influenced the degradation rate of anthocyanin pigments during storage. Under cold chain conditions (4 °C), fructose provided notable protection for anthocyanins (36.2% loss), whereas erythritol resulted in the highest pigment loss (78.0%) (Scrob et al., 2022b). In contrast, Nowicka and Wojdyło (2016) reported that cherry purees prepared with sugar alcohols such as erythritol and xylitol showed a protective effect on anthocyanin content after 6 months of storage, with both sugar alcohols better preserving anthocyanins under cold conditions compared to sucrose. These findings suggest that the protective effects of sweeteners on anthocyanins may vary depending on the type of fruit and the specific food matrix composition, which may explain variations observed across similar formulations.

The changes in TPC of the soft candies during storage are shown in Fig. 3. Overall, samples stored at 4 °C maintained higher TPC levels than those stored at 20 °C, confirming the protective effect of lower temperature. However, for both storage conditions, no significant changes were observed in formulations over the 90 days (p>0.05).

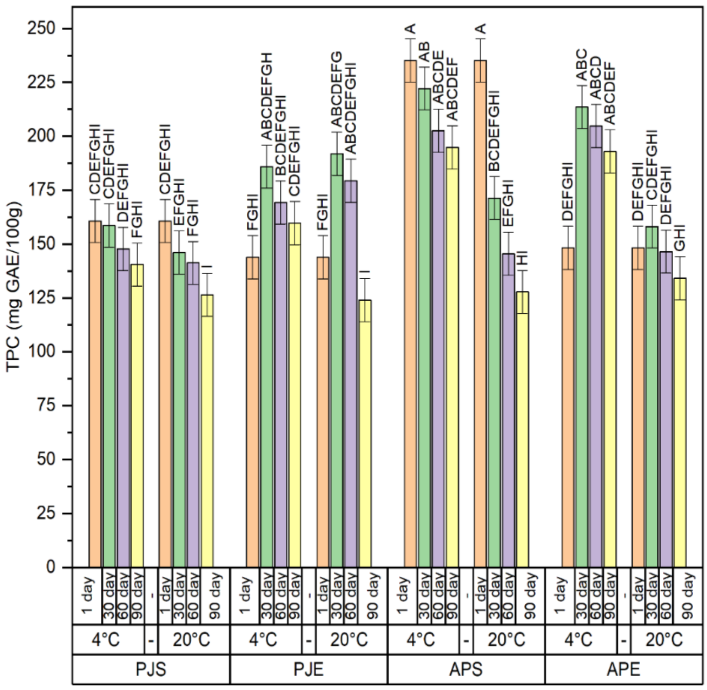

Figure 3. Changes in TPC values of soft candies during 90 days of storage at 4°C and 20°C. Different letters (A, B) indicate significant differences between samples (p<0.05). PJS: Pomegranate juice–based soft candies with sucrose; PJE: Pomegranate juice–based soft candies with erythritol; APS: Aronia puree–based soft candies with sucrose; APE: Aronia puree–based soft candies with erythritol

Likewise, the type of sweetener (sucrose vs. erythritol+sucralose) did not significantly affect phenolic retention. Although small fluctuations occurred, they were not statistically significant at most storage points (p>0.05), indicating the TPC of the soft candies remained stable over 90 days. These findings are in line with previous reports showing generally moderate phenolic losses during storage of fruit-based gels and candies (Casas-Forero et al., 2022; Tutunchi et al., 2019). In hydrogels enriched with cryo-concentrated blueberry juice, for example, TPC loss is approximately 50% for hydrogel products, both gelatin-gel and gummy types, during both cold and ambient storage over 35 days (Casas-Forero et al., 2022). Likewise, red beet–based gummies showed 25–35% reductions in TPC after 28 days (Tutunchi et al., 2019), and pomegranate concentrate–based gummy candy stored at ambient and dark conditions for 15 days showed a 23% reduction in TPC (Qi et al., 2023). In the present study, the observed stability may reflect the role of the sucrose/erythritol-incorporated gelatin-gellan gum network, and the naturally low pH of the candies (3.69–3.87) also contributes to an additional stabilising environment for phenolics. Recent research by Toker et al. (2025) on red beet gummies demonstrates that the gelatin-sucrose network can act as a protective barrier. Sucrose interacts with gelatin to form a dense, cross-linked structure that significantly reduces molecular mobility and hinders the diffusion of oxygen, a primary driver of phenolic oxidation.

Changes in antioxidant activity (CUPRAC and DPPH) during storage are shown in Figs. 4–5.

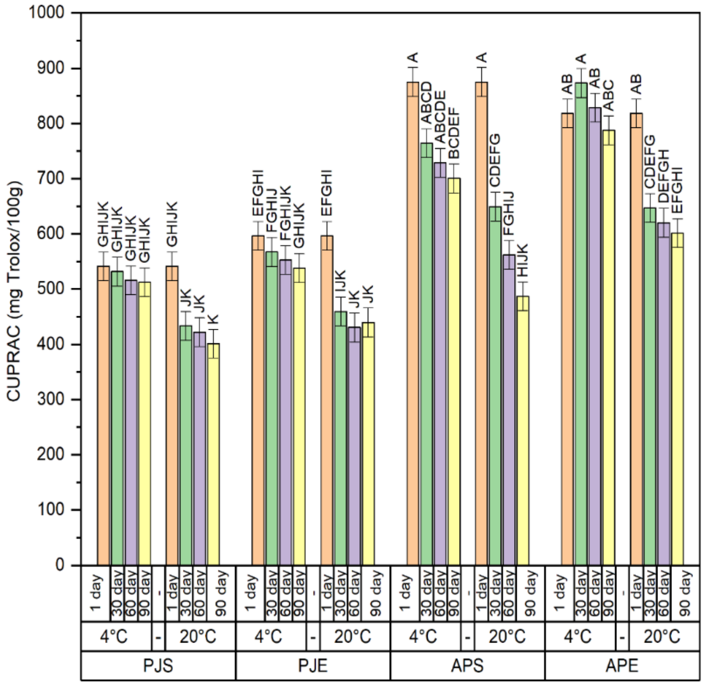

Figure 4. Changes in CUPRAC values of soft candies during 90 days of storage at 4°C and 20°C. Different letters (A, B) indicate significant differences between samples (p<0.05). PJS: Pomegranate juice–based soft candies with sucrose; PJE: Pomegranate juice–based soft candies with erythritol; APS: Aronia puree–based soft candies with sucrose; APE: Aronia puree–based soft candies with erythritol

Both assays revealed a gradual decline over 90 days, with losses more pronounced at 20 °C than at 4 °C (p<0.05). At 20°C, CUPRAC values decreased sharply within the first 30 days, followed by a slower decline, while IC_{50} values showed a similar initial increase and then stabilised. In contrast, samples stored at 4 °C retained notably higher antioxidant activity throughout the 90-day period, highlighting refrigeration as an effective strategy for preserving antioxidant capacity. These findings align with previous studies reporting that antioxidant degradation during storage parallels anthocyanin losses, underscoring the strong contribution of anthocyanins and other phenolics to overall antioxidant potential in fruit-based systems (Sethi et al., 2020; Teneva et al., 2022). Although sweetener type did not significantly influence CUPRAC or DPPH values (p>0.05), erythritol-containing formulations (APE) showed higher CUPRAC values than their sucrose-based counterparts (APS) at the end of storage. This difference may be attributed to erythritol's intrinsic antioxidant activity; as a polyol with multiple hydroxyl groups, it can scavenge hydroxyl radicals ($^{\cdot}OH$) and protect bioactive compounds from oxidative degradation (den Hartog et al., 2010).

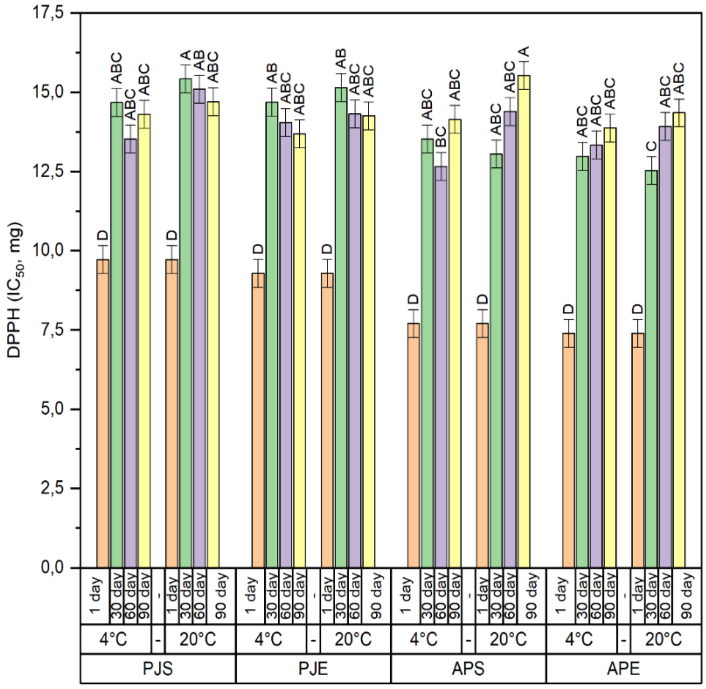

Figure 5. Changes in IC_{50} values of soft candies during 90 days of storage at 4°C and 20°C. Different letters (A, B) indicate significant differences between samples (p<0.05). PJS: Pomegranate juice–based soft candies with sucrose; PJE: Pomegranate juice–based soft candies with erythritol; APS: Aronia puree–based soft candies with sucrose; APE: Aronia puree–based soft candies with erythritol

Similar findings have been reported in other food matrices, where polyols contributed not only to sweetness but also to the stabilisation of sensitive bioactive compounds during storage (Chung et al., 2013). Therefore, while temperature remains the dominant factor influencing antioxidant preservation, polyol-based sweeteners such as erythritol may provide an additional protective effect against oxidative degradation.

Conclusion

This study demonstrated that enriching pomegranate concentrate-based soft candies with aronia puree substantially increased anthocyanin and phenolic contents, resulting in enhanced antioxidant activity and establishing aronia as a valuable functional ingredient. While sucrose-based formulations achieved higher initial anthocyanin levels, low-calorie sweeteners (erythritol and sucralose) provided better stability during storage, particularly at ambient temperature. Cold storage at 4 °C was identified as a critical factor for preserving nutraceutical integrity. These findings highlight the combined importance of ingredient selection and cold-chain management in producing functional confectionery products with improved health benefits. Despite these promising results, certain limitations should be noted. The sensory acceptability of aronia puree-based formulations requires broader evaluation, as inherent astringency and bitterness, aronia may affect consumer preference. In addition, the bioavailability of anthocyanins within the candy matrix was not assessed, leaving uncertainty regarding their physiological efficacy. Future research should therefore focus on optimising formulations while incorporating bioavailability assessments and comprehensive consumer testing. Collectively, this research provides a strong foundation for developing anthocyanin-rich functional candies that align with growing consumer demand for healthier confectionery options.

Author Contributions: AK, MAD and AC: Investigation, Laboratory analysis, Writing-Review and Editing; CUP: Project administration, Conceptualisation, Data analysis, Writing-Review and Editing.
Funding: This research was funded by Çanakkale Onsekiz Mart University Scientific Research Projects Coordination Unit (Project No: FHD-2022-4110).
Acknowledgements: None.
Conflicts of Interest: The authors declare no conflict of interest.

References

Ali, M. R., Mohamed, R. M., Abedelmaksoud, T. G. (2021): Functional strawberry and red beetroot jelly candies rich in fibers and phenolic compounds. *Food Systems* 4(2), 82–88. https://doi.org/10.21323/2618-9771-2021-4-1-82-88

AOAC (2000): *Official Methods of Analysis of the Association of Official Analytical Chemists,* 935.29, 943.02, 942.15, Washington, DC, USA, 17th edition.

Apak, R., Güçlü, K., Özyürek, M., Karademir, S. E. (2004): Novel total antioxidant capacity index for dietary polyphenols and vitamins C and E, using their cupric ion reducing capability in the presence of neocuproine: CUPRAC method. *Journal of Agricultural and Food Chemistry* 52(26), 7970–7981. https://doi.org/10.1021/jf048741x

Ayvaz, H., Cabaroglu, T., Akyildiz, A., Pala, C. U., Temizkan, R., Ağçam, E., Ayvaz, Z., Durazzo, A., Lucarini, M., Direito, R., Diaconeasa, Z. (2022): Anthocyanins: Metabolic digestion, bioavailability, therapeutic effects, current pharmaceutical/industrial use, and innovation potential. *Antioxidants* 12(1), 48. https://doi.org/10.3390/antiox12010048

Benvenuti, S., Pellati, F., Melegari, M., Bertelli, D. (2004): Polyphenols, anthocyanins, ascorbic acid, and radical scavenging activity of Rubus, Ribes, and Aronia. *Journal of Food Science* 69(3), C164–C169. https://doi.org/10.1111/j.1365-2621.2004.tb13352.x

Boyaci, S., Polat, Ş., Kafkas, N. E. (2023): Determination of the phytochemical contents and pomological properties of chokeberry (*Aronia melanocarpa* L.) fruit in different harvesting periods. *Turkish Journal of Agriculture and Forestry* 47(6), 842–850. https://doi.org/10.55730/1300-011x.3132

Cano-Lamadrid, M., Calín-Sánchez, Á., Clemente-Villalba, J., Hernández, F., Carbonell-Barrachina, Á. A., Sendra, E., Wojdyło, A. (2020): Quality parameters and consumer acceptance of jelly candies based on pomegranate juice “Mollar de Elche.” *Foods* 9(4), 516. https://doi.org/10.3390/foods9040516

Casas-Forero, N., Trujillo-Mayol, I., Zúñiga, R. N., Petzold, G., Orellana-Palma, P. (2022): Effects of cryoconcentrated blueberry juice as functional ingredient for preparation of commercial confectionary hydrogels. *Gels* 8(4), 217. https://doi.org/10.3390/gels8040217

Chung, K., Banik, S. M., De Crisci, A. G., Pearson, D. M., Blake, T. R., Olsson, J. V, Ingram, A. J., Zare, R. N., Waymouth, R. M. (2013): Chemoselective Pd-catalyzed oxidation of polyols: synthetic scope and mechanistic studies. *Journal of the American Chemical Society* 135(20), 7593–7602. https://doi.org/10.1021/ja4008694

da Silva, L. B., Annetta, F. E., Alves, A. B., Queiroz, M. B., Fadini, A. L., da Silva, M. G., Efraim, P. (2016): Effect of differently processed açai (*Euterpe oleracea* Mart.) on the retention of phenolics and anthocyanins in chewy candies. *International Journal of Food Science and Technology* 51(12), 2603–2612. https://doi.org/10.1111/ijfs.13245

den Hartog, G. J. M., Boots, A. W., Adam-Perrot, A., Brouns, F., Verkooijen, I. W. C. M., Weseler, A. R., Haenen, G. R. M. M., Bast, A. (2010): Erythritol is a sweet antioxidant. *Nutrition* 26(4), 449–458. https://doi.org/10.1016/j.nut.2009.05.004

Denev, P., Kratchanova, M., Petrova, I., Klisurova, D., Georgiev, Y., Ognyanov, M., Yanakieva, I. (2018): Black chokeberry (*Aronia melanocarpa* (Michx.) Elliot) fruits and functional drinks differ significantly in their chemical composition and antioxidant activity. *Journal of Chemistry* 2018(1), 9574587. https://doi.org/10.1155/2018/9574587

Efe, N., Dawson, P. (2022): A review: sugar-based confectionery and the importance of ingredients. *European Journal of Agriculture and Food Sciences* 4(5), 1–8. https://doi.org/10.24018/ejfood.2022.4.5.552

Giusti, M. M., Wrolstad, R. E. (2001): Characterization and measurement of anthocyanins by UV-visible spectroscopy. *Current Protocols in Food Analytical Chemistry* 1, F1.2.1.–F1.2.13 https://doi.org/10.1002/0471142913.faf0102s00

Grembecka, M. (2015): Sugar alcohols—their role in the modern world of sweeteners: a review. *European Food Research and Technology* 241(1), 1–14. https://doi.org/10.1007/s00217-015-2437-7

Groh, I. A. M., Bakuradze, T., Pahlke, G., Richling, E., Marko, D. (2020): Consumption of anthocyanin-rich beverages affects Nrf2 and Nrf2-dependent gene transcription in peripheral lymphocytes and DNA integrity of healthy volunteers. *BMC Chemistry* 14(1), 39. https://doi.org/10.1186/s13065-020-00690-6

Kaloudi, T., Tsimogiannis, D., Oreopoulou, V. (2022): *Aronia melanocarpa*: Identification and exploitation of its phenolic components. *Molecules* 27(14), 4375. https://doi.org/10.3390/molecules27144375

Kapoor, P., Tiwari, A., Sharma, S., Tiwari, V., Sheoran, B., Ali, U., Garg, M. (2023): Effect of anthocyanins on gut health markers, Firmicutes-Bacteroidetes ratio and short-chain fatty acids: a systematic review via meta-analysis. *Scientific Reports* 13(1), 1729. https://doi.org/10.1038/s41598-023-28764-0

Konar, N., Khiabani, A. H., Atar, H. H., Polat, D. G., Durmaz, Y., Mert, B. (2025): Potential application of the encapsulated microalgae biomass as an innovative ingredient in gummy formulation. *Journal of Food Measurement and Characterization* 19(8), 6095–6107. https://doi.org/10.1007/s11694-025-03378-4

Lao, F., Giusti, M. M. (2017): The effect of pigment matrix, temperature and amount of carrier on the yield and final color properties of spray dried purple corn (*Zea mays* L.) cob anthocyanin powders. *Food Chemistry* 227, 376–382. https://doi.org/10.1016/J.FOODCHEM.2017.01.091

Lemus-Mondaca, R., Vega-Gálvez, A., Zura-Bravo, L., Ah-Hen, K. (2012): *Stevia rebaudiana* Bertoni, source of a high-potency natural sweetener: A comprehensive review on the biochemical, nutritional and functional aspects. *Food Chemistry* 132(3), 1121–1132. https://doi.org/10.1016/j.foodchem.2011.11.140

Li, F., Sun, Q., Chen, L., Zhang, R., Zhang, Z. (2025): Unlocking the health potential of anthocyanins: a structural insight into their varied biological effects. *Critical Reviews in Food Science and Nutrition* 65(11), 2134–2154. https://doi.org/10.1080/10408398.2024.2328176

Lv, X., Lan, T., Wang, S., Li, X., Bao, S., Li, T., Sun, X., Ma, T. (2024): Comparative study on the physicochemical properties, functional components, color and anthocyanins profile of *Aronia melanocarpa* juice using different sterilization methods. *Food Innovation and Advances* 3(2), 64–74. https://doi.org/10.48130/fia-0024-0008

Mazi, T. A., Stanhope, K. L. (2023): Erythritol: an in-depth discussion of its potential to be a beneficial dietary component. *Nutrients* 15(1), 204. https://doi.org/10.3390/nu15010204

Meilgaard, M. C., Carr, B. T., Civille, G. V. (1999): *Sensory evaluation techniques, 3rd ed*. CRC press. Boca Raton, p. 416.

Moazzem, M. S., Williams, R., Hayden, M., D'Souza, N., Cho, S. (2025): Taste profiles of steviol glycoside blends and their application in ice cream. *International Journal of Gastronomy and Food Science* 40, 101143. https://doi.org/10.1016/j.ijgfs.2025.101143

Mutlu, C., Tontul, S. A., Erbaş, M. (2018): Production of a minimally processed jelly candy for children using honey instead of sugar. *LWT-Food Science and Technology* 93, 499–505. https://doi.org/10.1016/j.lwt.2018.03.064

Nour, V. (2022): Quality characteristics, anthocyanin stability and antioxidant activity of apple (*Malus domestica*) and black chokeberry (*Aronia melanocarpa*) juice blends. *Plants* 11(15), 2027. https://doi.org/10.3390/plants11152027

Nowicka, P., Wojdyło, A. (2016): Stability of phenolic compounds, antioxidant activity and colour through natural sweeteners addition during storage of sour cherry pulp. *Food Chemistry* 196, 925–934. https://doi.org/10.1016/j.foodchem.2015.10.019

Pala, Ç. U., Toklucu, A. K. (2011): Effect of UV-C light on anthocyanin content and other quality parameters of pomegranate juice. *Journal of Food Composition and Analysis* 24(6), 790–795. https://doi.org/10.1016/j.jfca.2011.01.003

Patras, A., Brunton, N. P., O'Donnell, C., Tiwari, B. K. (2010): Effect of thermal processing on anthocyanin stability in foods; mechanisms and kinetics of degradation. *Trends in Food Science and Technology* 21(1), 3–11. https://doi.org/10.1016/j.tifs.2009.07.004

Perko, R., DeCock, P. (2006): Erythritol. In *Sweeteners and Sugar Alternatives in Food Technology*; (H. Mitchell, ed.). Oxford: Blackwell Publishing, 149–176. https://doi.org/10.1002/9780470996003.ch9

Pratiwi, L. J., Swasti, Y. R., Pranata, F. S. (2023): The quality of red guava (*Psidium guajava* L.) gummy candies with variation additions of pineapple peel extract paste (*Ananas comoscus* L. Merr) as a gelling agent. *Food Research* 7(3), 63–70. https://doi.org/10.26656/fr.2017.7(3).796

Qi, N. A., Hasnan, N. Z. N., Basha, R. K., Alyas, N. D., Zulkifli, N. I. M. (2023): Physicochemical properties, bioactive compounds degradation kinetics, and microbiological counts of fortified pomegranate gummy candy (GC) during ambient storage. *Industria: Jurnal Teknologi dan Manajemen Agroindustri* 12(2), 103–117. https://doi.org/10.21776/ub.industria.2023.012.02.1

Renaldi, G., Junsara, K., Jannu, T., Sirinupong, N., Samakradhamrongthai, R. S. (2022): Physicochemical, textural, and sensory qualities of pectin/gelatin gummy jelly incorporated with *Garcinia atroviridis* and its consumer acceptability. *International Journal of Gastronomy and Food Science* 28, 100505. https://doi.org/10.1016/j.ijgfs.2022.100505

Riedel, R., Böhme, B., Rohm, H. (2015): Development of formulations for reduced-sugar and sugar-free agar-based fruit jellies. *International Journal of Food Science and Technology* 50(6), 1338–1344. https://doi.org/10.1111/ijfs.12787

Romulo, A. (2020): The principle of some in vitro antioxidant activity methods. *IOP Conference Series: Earth and Environmental Science* 426(1), 012177. https://doi.org/10.1088/1755-1315/426/1/012177

Salar, F. J., Agulló, V., Domínguez-Perles, R., García-Viguera, C. (2022): Influence of sweeteners (sucrose, sucralose, and stevia) on bioactive compounds in a model system study for citrus–maqui beverages. *Foods* 11(15), 2266. https://doi.org/10.3390/foods11152266

Salman, E., Guclu, G., Pehlivan, Z. Y., Kelebek, H., Selli, S. (2025): Changes in volatile, key odorants and bioactive properties of pomegranate juice during processing into concentrate. *Food Chemistry* 472, 142856. https://doi.org/10.1016/j.foodchem.2025.142856

Scrob, T., Hosu, A., Cimpoiu, C. (2022a): Sweeteners from different lingonberry jams influence on bioaccessibility of vitamin C, anthocyanins and antioxidant capacity under in vitro gastrointestinal digestion. *Antioxidants* 11(3), 442. https://doi.org/10.3390/antiox11030442

Scrob, T., Varodi, S. M., Vintilă, G. A., Casoni, D., Cimpoiu, C. (2022b): Estimation of degradation kinetics of bioactive compounds in several lingonberry jams as affected by different sweeteners and storage conditions. *Food Chemistry: X* 16, 100471. https://doi.org/10.1016/j.fochx.2022.100471

Sethi, S., Joshi, A., Arora, B., Bhowmik, A., Sharma, R. R., Kumar, P. (2020): Significance of FRAP, DPPH, and CUPRAC assays for antioxidant activity determination in apple fruit extracts. *European Food Research and Technology* 246(3), 591–598. https://doi.org/10.1007/s00217-020-03432-z

Singleton, V. L., Rossi, J. A. (1965): Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American Journal of Enology and Viticulture* 16(3), 144–158. https://doi.org/10.5344/ajev.1965.16.3.144

Székelyhidi, R., Giczi, Z., Pallag, R., Lakatos, E., Sik, B. (2024): Physicochemical and textural properties of gummy candies prepared with fruit vinegar. *Applied Food Research* 4(2), 100473. https://doi.org/10.1016/j.afres.2024.100473

Teneva, D., Pencheva, D., Petrova, A., Ognyanov, M., Georgiev, Y., Denev, P. (2022): Addition of medicinal plants increases antioxidant activity, color, and anthocyanin stability of black chokeberry (*Aronia melanocarpa*) functional beverages. *Plants* 11(3), 243. https://doi.org/10.3390/plants11030243

Toker, O. S., Atalar, I., Kurt, A., Palabiyik, I., Konar, N. (2025): Red beet extract powder, gelatin and sucrose interactions in gummy candies. *Foods* 14(17), 3138. https://doi.org/10.3390/foods14173138

Türkyılmaz, M., Hamzaoğlu, F., Uzun, M. A., Özkan, M. (2025): Use of tannase, paraoxonase-1 and cysteine protease as means to enhance copigmentation but reduce astringency in pomegranate juice. *Food Chemistry* 486, 144611. https://doi.org/10.1016/j.foodchem.2025.144611

Tutunchi, P., Roufegarinejad, L., Hamishehkar, H., Alizadeh, A. (2019): Extraction of red beet extract with β-cyclodextrin-enhanced ultrasound assisted extraction: A strategy for enhancing the extraction efficacy of bioactive compounds and their stability in food models. *Food Chemistry* 297, 124994. https://doi.org/10.1016/j.foodchem.2019.124994

Zhou, F., Wang, T., Zhang, B., Zhao, H. (2018): Addition of sucrose during the blueberry heating process is good or bad? Evaluating the changes of anthocyanins/anthocyanidins and the anticancer ability in HepG-2 cells. *Food Research International* 107, 509–517. https://doi.org/10.1016/j.foodres.2018.02.071