



## Research Article



# Morphometric Traits, Phenolic Content, and Antioxidant Capacity of *Crataegus pinnatifida* Bge. var. *major* N. E. Brown

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*Crataegus pinnatifida* Bge. var. *major* N. E. Brown is a traditional medicinal plant and an economically important fruit species widely used in pharmacology and functional food production due to its rich content of bioactive compounds. This study evaluated the morphological characteristics of fruits and seeds of *C. pinnatifida* var. *major* grown under Slovak conditions and assessed their antioxidant potential and the levels of selected bioactive compounds. Morphometric analysis revealed large fruit dimensions (25.40–32.39 mm in length, 28.96–38.68 mm in width, and 10.91–20.36 g in weight) and seeds with lengths of 8.65–12.93 mm, widths of 4.83–9.54 mm, and a single-seed weight of 0.71–3.33 mg. The total polyphenol content differed markedly between fruit tissues, ranging from 13,382 to 14,169 mg·kg<sup>-1</sup> in the mesocarp, while substantially higher values were detected in the exocarp (17,683 to 18,714 mg·kg<sup>-1</sup>), indicating a greater accumulation of phenolic compounds in the outer fruit tissues. Similarly, anthocyanin content was relatively low in the mesocarp (7.97 to 15.15 mg·kg<sup>-1</sup>) but dramatically higher in the exocarp (277.75 to 315.12 mg·kg<sup>-1</sup>), confirming that these pigments are predominantly localised in the peel. Antioxidant activity of the exocarp and mesocarp varied among tissues and extraction solvents. Acetone extracts exhibited the highest antioxidant activity in the exocarp (46.68%), whereas methanol showed the highest radical scavenging capacity in the mesocarp (34.78%), followed by ethanol (42.20% in the exocarp and 28.86% in the mesocarp). Water extracts provided consistently lower antioxidant values in both tissues (17.08% in the mesocarp and 16.02% in the exocarp). These findings highlight the high nutritional and functional value of *C. pinnatifida* var. *major*, support its potential use in health-promoting food products, and contribute valuable information for biodiversity conservation and genetic resource management.

**Keywords:** Chinese hawthorn, morphological variability, bioactive compounds, antioxidant potential

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## Introduction

The genus *Crataegus* L. is an ancient and one of the largest groups within the family Rosaceae Juss., comprising approximately 280 species predominantly distributed across temperate regions of East Asia, Europe, and eastern North America (Chang et al., 2002; Shang et al., 2020). Among them, *Crataegus pinnatifida* Bunge is widely distributed across northern China, Europe, and North America and has attracted increasing interest due to its medicinal, nutritional, and agronomic value (Zhang et al., 2022a; Li et al., 2023).

Phylogenetic analyses based on specific locus amplified fragment sequencing (SLAFseq) have revealed two independent speciation events among Chinese hawthorn taxa. Populations in southwestern China share a genetic pool with European species, whereas those in northeastern China likely originated from North American species (Du et al., 2019; Zhang et al., 2022b).

The medicinal application of *Crataegus pinnatifida* was first documented in *Xinxiu Ben Cao*. The dried fruits of *Crataegus pinnatifida* and its variety *C. pinnatifida* Bge. var. *major* N. E. Brown – commonly known as Chinese hawthorn or “Shanzha” – are recognised as a food-medicine homology herb with a long-standing tradition of therapeutic use in China (Li et al., 2023).

*Crataegus pinnatifida*, including *C. pinnatifida* Bunge and *C. pinnatifida* Bunge var. *major* N. E. Br., are the only taxa currently included in the Chinese Pharmacopoeia (Yang & Liu, 2012). These taxa have been extensively employed in traditional and modern medicine in China and Europe, particularly for the prevention and treatment of cardiovascular diseases (Edwards et al., 2012; Cloud et al., 2020) and gastrointestinal dysfunction (Gao and Feng, 1994; Wu et al., 2020). The cultivated *Crataegus pinnatifida* var. *major* represents a particularly significant medicinal and edible species, traditionally used to promote digestive function (Wu et al., 2014; Nazhand et al., 2020; Zhang et al., 2022b).

The fleshy fruits of *C. pinnatifida* are notable for their appealing taste, vibrant coloration, and high nutritional value. They are rich in diverse bioactive constituents, including flavonoids, triterpenoids, organic acids, phenolic compounds, procyanidins, and anthocyanins (Bac et al., 2012; Edwards et al., 2012; Yang and Liu, 2012; Xu et al., 2016; Wang et al., 2025). This complex phytochemical composition contributes to the multifunctional biological effects and wide-ranging applications of hawthorn fruits (Ma et al., 2024).

Hawthorn fruits (*Crataegus fructus*) are primarily utilised as medicinal raw materials, and preparations derived from them exhibit lipid-lowering, anti-atherosclerotic, hypotensive, and cardioprotective effects (Antsyshkina et al., 1990; Evdokimova, 1999; Samylina et al., 2010). Additional biological activities have been reported for other plant parts, such as anticataract effects of leaves (Wang et al., 2011) and cytoprotective activity (Li et al., 2025). Specifically, *C. pinnatifida* fruits have demonstrated beneficial effects in dyslipidaemia management (Niu et al., 2011), anti-inflammatory activity (Kao et al., 2005), and anti-atherosclerotic action (Zhang et al., 2013). Despite these well-documented health-promoting properties, Chinese hawthorn remains an underutilised fruit species.

Although numerous studies have focused on the phytochemical composition and pharmacological effects of *C. pinnatifida*, less attention has been paid to the integration of morphological characterisation with biochemical and antioxidant assessment, particularly under European cultivation conditions. Moreover, while individual bioactive compounds – such as the flavonoid glycosides pinnatifida C and pinnatifida D isolated from the leaves of *C. pinnatifida* var. *major* (Zhang et al., 2001) – have been identified, comprehensive evaluations linking fruit and seed morphology with antioxidant potential remain limited.

Therefore, the present study aimed to evaluate a collection of *Crataegus pinnatifida* var. *major* cultivated under Slovak conditions by analysing selected morphological characteristics of fruits and seeds for classification, cataloguing, and long-term conservation, while simultaneously assessing their phytochemical composition and antioxidant potential.

## Material and Methodology

### Biological material

The species name was determined according to the nomenclature provided in *Flora of China* (2025). Mature fruits of *C. pinnatifida* var. *major* grown in Slovakian conditions (Nitra region – located in south-western Slovakia, 48° 19′ 11″ N, 18° 22′ 08″ E, with an altitudinal range of 135–217 m a.s.l.), were taken in October 2025. The specimens were stored in the herbarium and analysed in the laboratory of experimental botany at AgroBioTech Research Centre at the Slovak University of Agriculture in Nitra (Slovakia).

All measurements and analyses were performed on fresh raw material. All biochemical procedures were conducted in triplicate.

### Morphometric analyses

Morphological traits of 150 fruits collected from five genotypes ( $n = 150$ ), represented by individual trees grown under the same cultivation and climatic conditions, were evaluated. The analysed fruit parameters included fruit weight (g), fruit length (mm), fruit width (mm), and stem length (mm).

In addition, 175 seeds ( $n = 175$ ; 35 seeds per genotype) were analysed for seed weight (g), seed length (mm), seed width (mm), and seed shape index (length/width, L/W).

Fruit and seed weights were measured using a digital scale (Kern ADB-A01S05, Kern & Sohn GmbH, Germany) with a precision of 0.01 g. Linear dimensions were determined using a digital calliper (METRICA 111-012, Czech Republic) with a precision of 0.02 mm.

Images of fruits and seeds were captured using a stereomicroscope (ZEISS SteREO Discovery.V20, Carl Zeiss MicroImaging GmbH, Göttingen, Germany) equipped with digital cameras (Fujifilm FinePix S7000 and Panasonic DMC-FZ50).

### Biochemical analyses

#### Extract preparation

Polyphenol and anthocyanin contents were determined in the exocarp and mesocarp of fresh hawthorn fruits. Antioxidant activity was evaluated in four types of extracts: methanolic, ethanolic, aqueous, and acetone. The exocarp and mesocarp were manually separated prior to extraction.

Extraction was performed by mixing 1 g of sample with 10 mL of solvent (70% ethanol, 99.5% methanol,  $\geq 99.5\%$  acetone, or distilled water) and incubating for 12 h at 22 °C with continuous agitation. The extracts were subsequently filtered and used for further analyses.

#### Reagents

All chemicals were of analytical grade and obtained from Reachem (Slovakia), Centralchem s.r.o. (Bratislava, Slovakia), Sigma-Aldrich (USA), and VWR Chemicals (Belgium). The following reagents were used: ethanol (p.a.), methanol (p.a.), acetone, Folin–Ciocalteu reagent (2 N), DPPH (2,2-diphenyl-1-picrylhydrazyl), hydrochloric acid (HCl), sodium carbonate ( $\text{Na}_2\text{CO}_3$ ),

disodium hydrogen phosphate ( $\text{Na}_2\text{HPO}_4$ ), and citric acid.

### Instruments

Analyses were performed using a Rotofix 32 A centrifuge (Hettich, Germany), a Jenway 6405 UV/Vis spectrophotometer (Bibby Scientific Ltd., UK), a GENESYS 20 spectrophotometer (Thermo Fisher Scientific, USA), and a vortex mixer (IKA Vortex 3, Germany).

### Determination of total polyphenols

The total polyphenol content was determined spectrophotometrically using the Folin–Ciocalteu method (Lachman, 2003). Gallic acid served as the calibration standard. For each sample, 1 g of homogenized fresh raw material was extracted with 10 ml of 70% ethanol and shaken for 16 hours. The extracts were then filtered, and 1 ml of the filtrate was diluted to 50 ml with distilled water. Subsequently, 2.5 ml of Folin–Ciocalteu reagent and, after 3 minutes, 5 ml of 20%  $\text{Na}_2\text{CO}_3$  were added, and the solution was made up to volume. After a 2-hour colour development period, absorbance was measured at 765 nm using a JENWAY 6405 UV/Vis spectrophotometer. Polyphenol concentrations were calculated from the gallic acid calibration curve and expressed as mg GAE per kg fresh weight (FW).

### Determination of the anthocyanins

Anthocyanin content was determined using the method of Lapornik et al. (2005), which relies on lowering the extract pH to 0.5–0.8 to convert all anthocyanins into the red flavylium cation. One millilitre of extract was mixed with 1 ml of 0.01% HCl in 80% ethanol. For measurement, 10 ml of 2% aqueous HCl (set A1) or 10 ml of McIlvaine buffer at pH 3.5 (set A2) were added. Control tubes (A3, A4) were prepared analogously using distilled water. Absorbance was recorded at 520 nm against a blank using a JENWAY 6405 UV/Vis spectrophotometer. Total anthocyanins were calculated from the absorbance differences and expressed as  $\text{mg}\cdot\text{kg}^{-1}$  of extract (FW).

### DPPH free radical scavenging activity assay

DPPH solution (0.003%) was prepared in 70% ethanol. For the assay, 1,950  $\mu\text{L}$  of DPPH solution was mixed with 50  $\mu\text{L}$  of extract. After incubation in the dark for 10 min at room temperature, absorbance was measured at 515 nm, determined spectrophotometrically (GENESYS 20 Vis Spectrophotometer). Radical scavenging activity (%) was calculated as:

$$\% \text{ inhibition} = \left[ \frac{A_0 - A_{10}}{A_0} \right] \times 100$$

where:  $A_0$  is the absorbance of the control;  $A_{10}$  is the absorbance after 10 min of reaction

### Statistical analysis

Data were evaluated using descriptive statistics, including mean, minimum, maximum, and coefficient of variation (CV, %). Differences among variables were analysed using one-way analysis of variance (ANOVA) at a significance level of  $p \leq 0.05$ . Relationships among variables were assessed using Pearson’s correlation analysis. All statistical analyses were performed using STATISTICA 10 software (StatSoft Inc., USA).

## Results and Discussion

### Morphological characteristics

Morphological evaluation is essential for the identification of genotypes and the selection of valuable genetic resources for breeding and biodiversity conservation (Horčinová Sedláčková et al., 2020, 2021, 2024; Grygorieava et al., 2021, 2023; Zhurba et al., 2021; Levon et al., 2022).

Among the studied taxa, *C. pinnatifida* var. *major* was characterised by significantly larger and heavier fruits compared with other *Crataegus* species. Mean fruit dimensions reached approximately 29 mm in length, 33 mm in width, and 14.6 g in weight (Table 1). In

**Table 1** Morphological features of fruits of the genus *Crataegus* L.

Species	Author	Qualitative and quantitative features				
		shape	colour	length (mm)	width (mm)	weight fruits (g)
<i>Crataegus pinnatifida</i> var. <i>major</i>	Our results	rounded	dark red	29.05 ± 0.22	32.93 ± 0.28	14.63 ± 0.29
<i>C. pinnatifida</i>	Flora of China Editorial Committee (2003)	pear-shaped, (pyriform), subspheroidal	dark red with spots	1.00–2.50	1.00–2.50	–*
<i>C. laevigata</i>	Dvirna et al. (2021)	spherical (short-ellipsoidal)	brownish red, brown, black	7.60 ± 0.90	6.60 ± 0.75	–*
<i>C. monogyna</i>	Dvirna et al. (2021)	widely-short-ellipsoid, ovoid, rounded	dark red, brownish red	7.60 ± 0.95	5.70 ± 0.70	–*
	Obideen et al. (2024)	oval to slightly oblong, nearly round	redish	7.60	5.50	3.80
<i>C. azarolus</i>	Obideen et al. (2024)	rounded	red, yellow	1.56–1.58	1.82–2.08	4.55–6.34
<i>C. pentagyna</i>	Dvirna et al. (2021)	almost spherical, short-ellipsoidal	black, purple-black	8.90 ± 1.50	7.2 ± 0.50	–*
<i>C. sanguina</i>	Dvirna et al. (2021)	spherical (short-ellipsoidal)	blood red (brownish red)	8.60 ± 0.90	8.10 ± 0.70	–*
<i>C. fallacina</i>	Dvirna et al. (2021)	ellipsoidal or ovoid-ellipsoidal	yellowish-brown or red	8.60 ± 0.90	8.10 ± 0.70	–*
<i>C. rhipidophylla</i>	Dvirna et al. (2021)	elongated-ellipsoidal, ellipsoidal, cylindrical	dark red, yellow, burgundy, black	12.60 ± 2.74	1.3–2 times greater	–*
<i>C. pseudokyrstostyla</i>	Dvirna et al. (2021)	elongated-ellipsoidal, cylindrical	dark red, with green spots, reddish-brown	10.10 ± 0.45	5.45 ± 0.35	–*

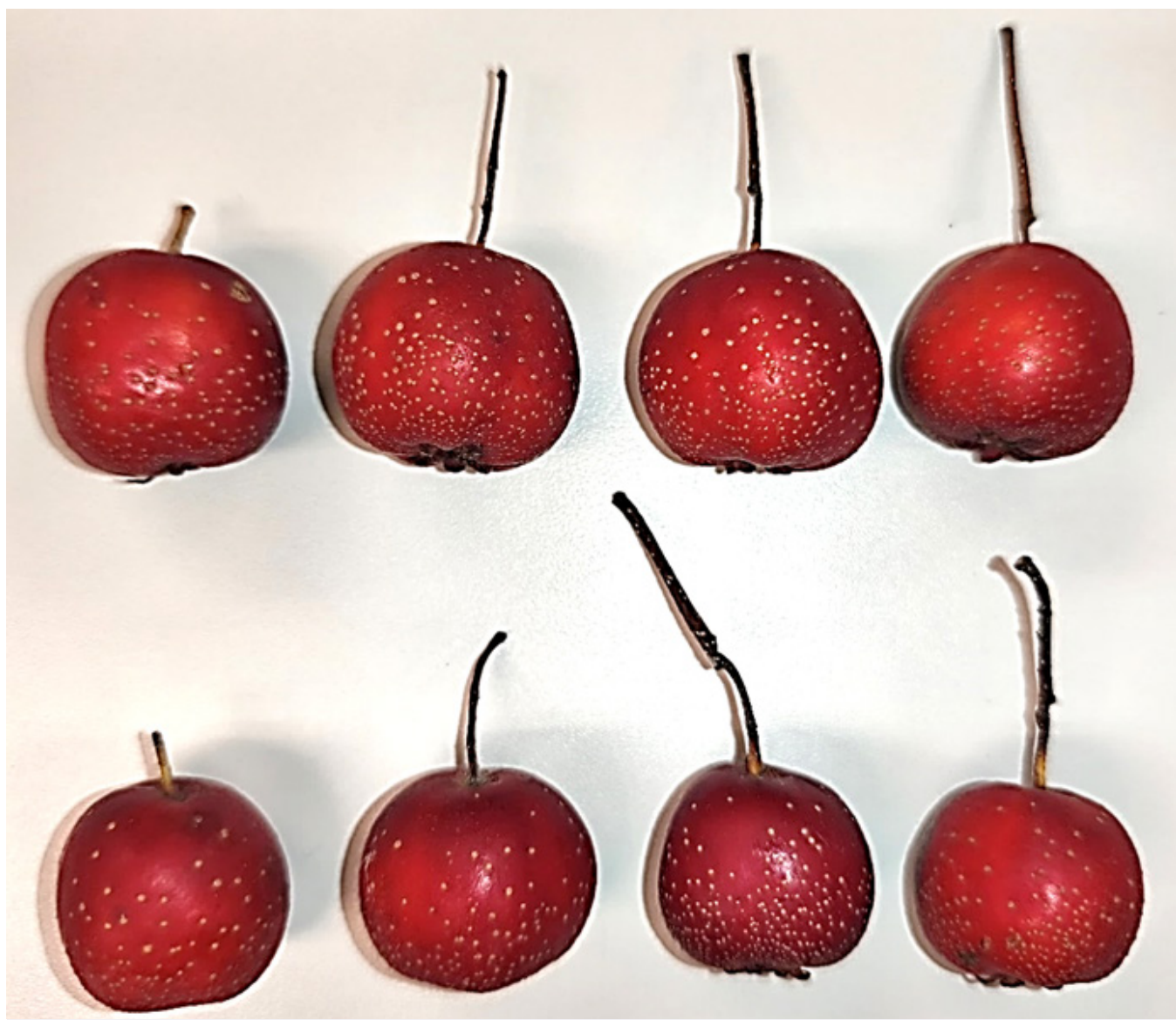
Notes: –\* ND (not determined)

contrast, species such as *C. monogyna* Jacq., *C. laevigata* (Poir.) DC., and *C. pentagyna* Waldst. & Kit. ex Willd. typically produce smaller fruits, generally ranging from 7–9 mm in length and 6–8 mm in width.

Our morphometric analysis confirmed considerable variability in fruit size, with fruit length ranging from 25.40 to 32.39 mm (CV = 5.29%), width from 28.96 to 38.68 mm (CV = 6.00%), and weight from 10.91 to 20.36 g (CV = 13.92%). Stem length showed the highest variability (5.00–49.13 mm; CV = 53.98%), indicating substantial heterogeneity among genotypes. The fruits were predominantly rounded to subspheroidal, with a characteristic dark red coloration and lighter surface spots, consistent with previous descriptions (Flora of China Editorial Committee, 2003).

The number of seeds per fruit ranged from three to five, which corresponds with published data. Seed morphometric traits also exhibited notable variability. Seed length ranged from 8.65 to 12.93 mm (CV = 9.05%), width from 4.83 to 9.54 mm (CV = 12.89%), and seed weight varied between 0.71 and 3.33 mg (CV = 27.45%). The shape index (L/W) ranged from 1.10 to 2.13 (CV = 11.43%).

Compared with previous studies, the seed dimensions observed in this study were generally larger. Muradoğlu et al. (2021) reported seed lengths ranging from 1.36 mm in *Crataegus monogyna* to 4.33 mm in *C. orientalis*, with seed weights between 0.23 g and 0.45 g. Similarly, Çalışkan et al. (2018) reported seed sizes of 2.40–2.50 mm and weights of 0.6–0.8 g across



**Figure 1A** Morphological variability of fruits of *Crataegus pinnatifida* var. *major*: variation in fruit shape and colour  
Photo: Miroslav Bella, 2025



**Figure 1B** Morphological variability of fruits of *Crataegus pinnatifida* var. *major*: Variation in the depth of the stalk cavity and eye basin  
Photo: Miroslav Bella, 2025

different hawthorn species. In contrast, the present study recorded substantially larger seed dimensions, with lengths of 8.65–12.93 mm and widths of 4.83–9.54 mm, although seed weight ranged from 0.71 to 3.33 mg.

These differences may be attributed to genotypic variation, environmental conditions, and cultivation practices. In particular, the larger seed size observed under Slovak conditions suggests a strong influence of local agroclimatic factors on fruit and seed development in *C. pinnatifida* var. *major*.

The fruits of *C. pinnatifida* var. *major* are characterised by a predominantly rounded to subspheroidal shape and an intense dark red coloration with lighter surface spots, which represent typical diagnostic features of this taxon. As shown in Figure 1, the fruits exhibit considerable size as well as variability in the depth of

the stalk cavity and eye basin, traits that are important for genotype differentiation and pomological evaluation.

Longitudinal and cross-sections (Figure 2) reveal a well-developed fleshy mesocarp surrounding multiple pyrenes (seeds), typically three to five per fruit. A clear structural distinction between the exocarp and mesocarp is evident, supporting subsequent tissue-specific analyses of bioactive compounds and antioxidant activity.

The seeds are elongated to ovate, with a smooth surface and brown to dark-brown coloration. Variability in seed length, width, and shape index (Figure 3) indicates a considerable degree of intraspecific morphological diversity.



**Figure 2** Comparison of selected fruits n of *Crataegus pinnatifida* Bge. var. *major* N. E. Brown in longitudinal and cross-sectional views  
Photo: Miroslav Bella, 2025



**Figure 3** Variation in seed shape and colour of selected samples of *Crataegus pinnatifida* Bge. var. *major* N. E. Brown  
Photo: Miroslav Bella, 2025

These seed traits represent valuable descriptors for taxonomic identification, genotype discrimination, and the evaluation of reproductive potential. In addition to fruit characteristics, seed biometric parameters constitute an important component in assessing genetic variability and the agronomic significance of *Crataegus* species.

### Polyphenol content

*Crataegus pinnatifida* fruits are rich in polyphenolic compounds, including epicatechin, procyanidins, chlorogenic acid, hyperoside, and isoquercitrin, which exhibit strong antioxidant activity (Jurikova et al., 2012; Zhang et al., 2020; Shu et al., 2023).

In the present study, total polyphenol content in the mesocarp ranged from 13,382 ±522 to 14,169 ±710 mg·kg<sup>-1</sup> fresh weight, whereas significantly higher values were observed in the exocarp (17,683 ±550 to 18,714 ±745 mg·kg<sup>-1</sup> FW). This confirms a pronounced accumulation of phenolic compounds in the outer fruit tissues (Table 2).

Zurek et al. (2024) investigated the content of polyphenolic compounds, flavonoids, and total proanthocyanidins in various hawthorn species and different morphological plant parts. The total polyphenol content ranged from 72.0 mg GAE·g<sup>-1</sup> in the flowers of *C. laevigata* to 243.9 mg GAE·g<sup>-1</sup> in the fruits of the hybrid *C. laevigata* × *rhipidophylla* × *monogyna*. Flavonoid content varied from 11.9 mg QE·g<sup>-1</sup> in the leaves of *C. rhipidophylla* to 86.8 mg QE·g<sup>-1</sup> in the fruits of *C. × subsphaericea*, while total proanthocyanidins ranged from 6.5 mg CYE·g<sup>-1</sup> in the flowers of *C. laevigata* to 45.6 mg CYE·g<sup>-1</sup> in the fruits of *C. rhipidophylla*.

Overall, their results demonstrated that fruits generally contained higher average levels of total polyphenols and proanthocyanidins, whereas the highest flavonoid concentrations were more frequently observed

in flowers. Among the studied taxa, the highest total polyphenol content was recorded in fruits and leaves of the hybrid *C. laevigata* × *rhipidophylla* × *monogyna* and in flowers of *C. rhipidophylla*. The highest flavonoid content occurred in fruits of *C. × subsphaericea*, leaves of *C. × macrocarpa*, and flowers of *C. laevigata* × *rhipidophylla* × *monogyna*. In contrast, the highest proanthocyanidin levels were detected in fruits of *C. rhipidophylla*, leaves of *C. laevigata*, and flowers of *C. × subsphaericea* (Zurek et al., 2024).

In *C. pinnatifida* var. *major*, procyanidins have been reported to accumulate rapidly during early fruit development, reaching up to 14 g·kg<sup>-1</sup> fresh weight (FW), followed by a gradual decline to approximately 4 g·kg<sup>-1</sup> FW at full ripening (Ciu et al., 2006). This dynamic pattern indicates strong developmental regulation of phenolic metabolism.

Polyphenols in plant tissues are well recognized as potent antioxidants that scavenge reactive oxygen species, thereby reducing oxidative stress and contributing to the prevention of chronic non-communicable diseases. Due to these properties, polyphenols are considered important dietary bioactive compounds with significant implications for human health (Selvakumar et al., 2020; Li et al., 2023).

### Anthocyanin content

Anthocyanins are typically localized in fruit peel tissues, where they are responsible for the characteristic coloration of fruits (Zhao et al., 2022, 2023; Kuang et al., 2025). In *C. pinnatifida*, anthocyanins are the major pigment compounds of the exocarp; however, their detailed composition and concentration patterns are still insufficiently characterized. In addition to their role in pigmentation, anthocyanins are well-known dietary antioxidants that reduce oxidative stress and inflammation, thereby supporting the prevention of chronic diseases such as cardiovascular disorders,

**Table 2** Comparison of bioactive compounds in the mesocarp and exocarp of *Crataegus pinnatifida* Bge. var. *major* N. E. Brown, mg·kg<sup>-1</sup> FW

Content	Genotypes				
	GP-01	GP-02	GP-03	GP-04	GP-05
<b>Exocarp</b>					
<b>Polyphenols</b>	18,417 ±550	18,714 ±745	17,882 ±774	17,683 ±550	17,927 ±588
<b>Anthocyanins</b>	283.81 ±16	283.81 ±15	277.75 ±12	281.79 ±15	315.12 ±18
<b>Mesocarp</b>					
<b>Polyphenols</b>	13,412 ±511	13,382 ±522	13,456 ±613	13,813 ±653	14,169 ±710
<b>Anthocyanins</b>	15.15 ±1.8	12.12 ±1.1	8.08 ±0.6	7.97 ±0.5	9.00 ±0.7

diabetes, and neurodegenerative conditions (Lila et al., 2016; Sandoval-Ramírez et al., 2021).

In the present study, anthocyanin content was significantly lower in the mesocarp, ranging from  $7.97 \pm 0.5$  to  $15.15 \pm 1.8$   $\text{mg}\cdot\text{kg}^{-1}$  FW, whereas markedly higher levels were detected in the exocarp ( $277.75 \pm 12$  to  $315.12 \pm 18$   $\text{mg}\cdot\text{kg}^{-1}$  FW). These results clearly demonstrate that anthocyanins are predominantly localized in the outer fruit tissues (Table 2), which have important nutritional and technological implications for the development of peel-derived functional ingredients and natural colorants.

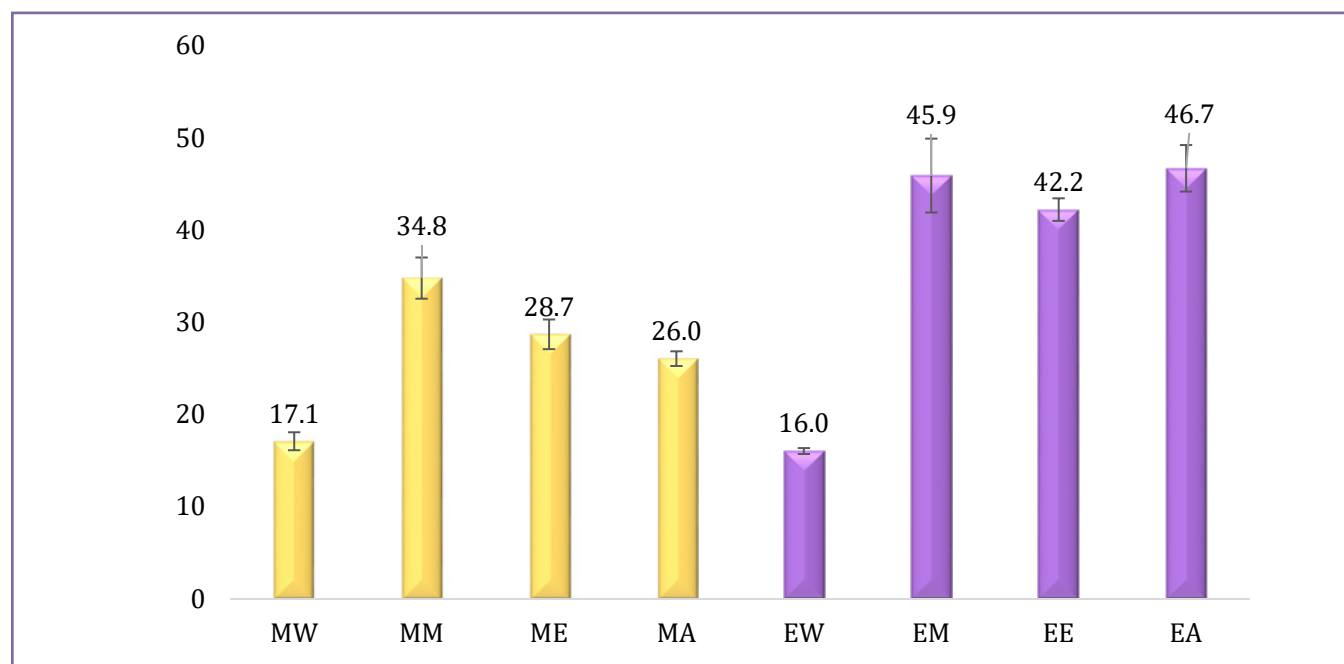
Similar tissue-specific distribution patterns have been reported in previous studies. Wang et al. (2025) using UPLC-ESI-MS/MS-based metabolomic analysis, compared anthocyanin profiles in red- and yellow-peel hawthorn cultivars and demonstrated significant differences in pigmentation parameters, including a lower hue angle in red peel ( $47.71 \pm 4.17$ ) compared with yellow peel ( $83.64 \pm 1.46$ ;  $p < 0.01$ ). These results indicate strong correlations between anthocyanin accumulation and fruit coloration.

Together, these findings and our results improve the understanding of anthocyanin localization and biosynthesis in hawthorn fruits and provide a basis for further exploitation of hawthorn peel as a source of natural anthocyanins.

### Antioxidant activity

The extraction efficiency differed markedly between the mesocarp and the exocarp, as well as among the solvents used. Hawthorn mesocarp extracts obtained with distilled water yielded the lowest antioxidant activity ( $15.62$ – $18.94$   $\text{mg}\cdot\text{kg}^{-1}$ ;  $\bar{x} = 17.08 \pm 0.98$ ), whereas methanol provided the highest values ( $30.32$ – $37.24$   $\text{mg}\cdot\text{kg}^{-1}$ ;  $\bar{x} = 34.78 \pm 2.23$ ). Intermediate antioxidant levels were obtained using ethanol ( $25.59$ – $31.02$   $\text{mg}\cdot\text{kg}^{-1}$ ;  $\bar{x} = 28.68 \pm 1.61$ ) and acetone ( $25.07$ – $27.62$   $\text{mg}\cdot\text{kg}^{-1}$ ;  $\bar{x} = 26.04 \pm 0.80$ ) extracts. In contrast, the exocarp consistently exhibited higher antioxidant potential across all solvents, with minimal extraction again observed in distilled water ( $15.69$ – $16.66$   $\text{mg}\cdot\text{kg}^{-1}$ ;  $\bar{x} = 16.02 \pm 0.32$ ) and the highest yields achieved using methanol ( $40.83$ – $53.81$   $\text{mg}\cdot\text{kg}^{-1}$ ;  $\bar{x} = 45.90 \pm 4.01$ ). Ethanol ( $39.94$ – $44.17$   $\text{mg}\cdot\text{kg}^{-1}$ ;  $\bar{x} = 42.20 \pm 1.23$ ) and acetone ( $43.55$ – $51.66$   $\text{mg}\cdot\text{kg}^{-1}$ ;  $\bar{x} = 46.68 \pm 2.52$ ) showed comparably elevated extraction efficiencies. Overall, methanol proved to be the most efficient solvent for both tissue types, while distilled water consistently yielded the lowest recoveries (Figure 4), with the higher activity of methanol and acetone extracts attributable to the superior solubility of bioactive compounds in these solvents and their antioxidant activity.

The antioxidant capacity of hawthorn was primarily associated with total polyphenolic content rather than with total anthocyanins or total flavonoids, a trend



**Figure 4** Comparison of antioxidant activity in mesocarp and exocarp of *C. pinnatifida* Bge. var. *major* N. E. Brown in various extracts, %: MW – mesocarp water extracts; MM – mesocarp methanol extracts; ME – mesocarp ethanol extracts; MA – mesocarp acetone extracts; EW – exocarp water extracts; EM – exocarp methanol extracts; EE – exocarp ethanol extracts; EA – exocarp acetone extracts

consistently reported in the literature (Liu et al., 2016; Alirezalu et al., 2020; Zurek et al., 2024).

Recent studies have further demonstrated that hawthorn pulp and its associated polyphenols exhibit considerable *in vitro* antioxidant activity; specifically, the total antioxidant capacity of hawthorn pulp has been reported to range from 0.32 to 1.84 mmol Fe<sup>2+</sup>·g<sup>-1</sup> dry weight (DW) (Alirezalu et al., 2020).

The predominance of polyphenols as key contributors to antioxidant activity is also influenced by extraction conditions, as Sultana et al. (2009) showed that aqueous methanol is more effective than ethanol or acetone for extracting polyphenolic compounds from various medicinal plant matrices.

In *Crataegus* spp. fruits, the major polyphenolic constituents include phenolic acids, flavonoids, and proanthocyanidins. The functional relevance of these compounds has been demonstrated in applied food studies. For example, Baran and Nadaroğlu (2022) investigated pestil, a traditional Turkish dried fruit product prepared from hawthorn pulp, and reported strong antioxidant activity associated with high phenolic content, highlighting its potential for industrial application as a functional food.

## Conclusion

The Slovak-grown *Crataegus pinnatifida* var. *major* exhibited significant variability in fruit and seed morphology, confirming its suitability for classification, conservation, and inclusion in local germplasm collections. The species demonstrated notable antioxidant potential, characterized by high polyphenol and anthocyanin contents, particularly in methanol and acetone extracts of the exocarp, reflecting its richness in phenolic and other bioactive compounds. These findings reinforce the importance of the Chinese hawthorn variety as a promising source of functional ingredients for food and pharmaceutical applications and highlight its potential use in functional foods and nutraceutical products. Moreover, the results provide valuable information on the adaptability and cultivation potential of this species under Central European conditions, contributing both to biodiversity preservation and the development of health-oriented products. Future research should focus on detailed phytochemical profiling, evaluation of additional biological activities, and agronomic studies aimed at optimizing cultivation performance.

## Conflict of interest

The authors have no competing interests to declare.

## Ethical statement

This article doesn't contain any studies that would require an ethical statement.

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