https://doi.org/10.17221/112/2023-CJFS

# Comparison of physicochemical properties, phenolic profiles and antioxidant capacity of hawthorn berries stored at different temperatures and time

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**Citation:** Wei X., Yin Y., Xu K., Wang T., Zhu C., Liu W., Guo M. (2023): Comparison of physicochemical properties, phenolic profiles and antioxidant capacity of hawthorn berries stored at different temperatures and time. Czech J. Food Sci., 41: 419–427.

**Abstract:** This research investigated the effect of different storage temperatures on the compositional changes, physicochemical characteristics, and functional properties of hawthorn berries. Storage at 25 °C resulted in the gradual decrease of the moisture, hardness, sugar, titratable acid, and colour of hawthorn berries. These changes decreased with decreasing storage temperature, and the minimal changes happened at frozen storage (–18 °C). Similarly, the decreasing rate of ascorbic acid, extractable polyphenol (EPP), and flavonoids during storage also decreased with reducing storage temperature (25 °C > 4 °C > –18 °C). Hydrolysable polyphenol (HPP) was relatively stable during the hawthorn storage, and non-extractable proanthocyanidins (NEPA) increased with decreasing temperature. Ferric reducing antioxidant power (FRAP) of EPP and HPP decreased at 25 °C, while polyphenolic oxidase (PPO) and peroxidase (POD) activities decreased. Decreasing the storage temperature can improve the stability of the nutritional properties, antioxidant capacity, and enzyme activity of hawthorn. The specific storage temperature depends on the final processing conditions and the purposes of the hawthorn berries.

**Keywords:** hawthorn berries; oxidative stability; phenolic profile; physicochemical quality; storage condition

Hawthorn (*Crataegus pinnatifida*), a member of the family Rosaceae, is mainly produced in the Northern Hemisphere, including China, Europe, and North America. Hawthorn berries have a long history of being used as a traditional dual-purpose raw material for both medicine and functional foods in China due to their abundant nutritional and functional components, including protein, sugar, organic acids, vitamins, anthocyanins, flavonoids, and so on (Liu et al. 2011). The total sugar and protein content in hawthorn is around 22% and 7%, respectively. Besides, hawthorn fruit contains large amounts of organic acids [3~6% dry basis (d.b.)], such as caffeic, malic, tartaric, and citric acids (Gao et al. 1995). Phenolic compounds

Supported by the the Weifang Science and Technology Bureau through the Science and technology development plan of Weifang city (Project No. 2018ZJ1112).

https://doi.org/10.17221/112/2023-CJFS

are the major bioactive compounds and natural antioxidants contributing to the antioxidant activity of hawthorn berries. Currently, more than 60 phenolic compounds have been isolated from hawthorn. Among them, procyanidins (procyanidin B2, procyanidin B5, and procyanidin C1), flavonoids (epicatechin, hyperoside, quercetin, rutin, and isoquercitrin), and triterpenoids acid (ursolic acid, corosolic acid, oleanolic acid, and maslinic acid) are the main bioactive components in hawthorn berries (Li et al. 2013). Previous studies have indicated that the beneficial effect of hawthorn berries on human health was closely correlated to the content of phenolic compounds, such as flavonoids and anthocyanins (Betina et al. 2022). In addition, Luo et al. (2009a) confirmed that the polyphenols obtained from hawthorn fruits exhibited *in vivo* hypolipidemic effects. As one of the typical climacteric fruits, water loss, browning, and other deterioration phenomena of hawthorn berries generally appear during the storage process, which would further cause the loss of nutrients and processing quality. However, appropriate postharvest storage methods were undoubtedly effective for maintaining the commercial and nutritional values of their climacteric fruits, such as winter jujube, navel orange, and prune (Sang et al. 2022). The postharvest life cycle of fruits is a complex oxidative process involving physiological and biochemical metabolism and can be divided into two stages: ripening and senescence (Batista et al. 2018). During storage, the physiological metabolism (metabolic enzyme activity, respiratory intensity, and transpiration) and the microbial infection of fruits depend on the storage temperature. Although a lower temperature is usually preferred to alleviate the deterioration and further extend the shelf-life of fruits (Wu et al. 2020), a too-low temperature (such as frozen) might cause damage to the fruit due to the loss of water and disruption of structure (Wang et al. 2015).

To date, there is limited research regarding the influence of storage temperature on the quality of hawthorn. Many questions still need to be answered, such as the maximum storage time of hawthorn berries at different temperatures, the effect of temperature variation on the organoleptic, nutritional, and functional characteristics of hawthorn berries, and so on. To further understand the influence of storage conditions on the quality of hawthorn berries, this research used room temperature (25 °C), cold storage (4 °C), and frozen storage (–18 °C) to store the hawthorn berries, and the changes in physicochemical quality, phenolic compounds, antioxidant capacities, polyphenolic oxidase (PPO) and peroxidase (POD) activities during the storage were evaluated. These results will provide theoretical guidance for selecting the appropriate storage and preservation methodology for the hawthorn processing industry.

## MATERIAL AND METHODS

**Material and chemicals.** Fresh hawthorn berries obtained from the Dajinxing cultivar were manually collected on the 138$^{th}$ day after full bloom day in the central mountainous region of Shandong province. Hawthorn berries with consistent maturity and no mechanical damage were used, which were then equally divided into three groups and stored at 25, 4, and –18 °C, respectively. All measurements were carried out before grouping and at 15, 30, 60, and 180 days during storage. Frozen hawthorn berries at –18 °C must be thawed at 25 °C for 2 h before further measurements. Folin & Ciocalteu's phenol reagent, 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,4,6-Tris(2-pyridyl)-s-triazine (TPTZ), and 2-methoxy-phenol were purchased from Sigma-Aldrich (USA). All other chemicals were of analytical grade.

**Physical indicators and proximate compositions.** At least 10 hawthorn berries with natural moisture were used to evaluate physical quality. Bulk density was calculated using the equation: mass (g)/volume (mL). Hardness was determined using a GY-3 fruit hardness tester (THY Science Technology Co., Ltd, China). The surface colour of hawthorn berries was directly measured using a CR 400 chromameter (Minolta Camera Co., Japan) with a white calibration plate.

Moisture was determined by the American Association of Cereal Chemists (AACC)-approved method 44-15.02 (AACC 1999). Reducing sugar and total sugar concentrations were measured according to the previous methods of Gu et al. (2022). Titratable acidity (TA) was determined by titration with 0.1 mol·L$^{-1}$ NaOH expressing as gram of citric acid equivalents per 100 g dry matter. Ascorbic acid content was measured using the methods of Li et al. (2015).

**Phenolic fractions and their antioxidant capacity.** The extraction and determination of extractable polyphenol (EPP), hydrolysable polyphenol (HPP), and non-extractable proanthocyanidins (NEPA) were carried out according to the procedure described by Pico et al. (2019). Total phenolic content was determined using Folin-Ciocalteu's method. Ferric reducing antioxidant power (FRAP) assay was operated according to the procedure described by Benzie and Strain (1996). DPPH radical scavenging capacity (DPPH-RSC)

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was measured using the method of Pico et al. (2019). All measurements were performed in triplicate, and the results were expressed on a dry basis.

**Determination of total flavonoids.** Total flavonoids were quantified using the aluminium chloride colourimetric assay described by Abu Bakar et al. (2009).

**Polyphenolic oxidase and peroxidase activity assay.** Extraction and activity assay of crude enzymes were carried out by the method of Zhang and Shao (2015) with slight modification. Briefly, 1.0 g of hawthorn flour was homogenised in 20 mL of 0.1 mol·L$^{-1}$ phosphate buffer (PBS; pH = 6.8) containing 1 mmol·L$^{-1}$ ascorbic acid and 0.15 g·(100 mL)$^{-1}$ PVPP for 20 min at 4 °C. The homogenate was centrifuged at 8 000 r·min$^{-1}$ for 15 min at 4 °C. The supernatant was collected for PPO and POD activity assay.

**Statistical analysis.** All analyses were run in triplicate. Data were expressed as the mean ± standard deviation (SD). Differences among results were studied by one way analysis of variance (ANOVA) using Fisher's least significant difference (LSD) to describe means with 95% confidence intervals ($P < 0.05$).

## RESULTS AND DISCUSSION

**Changes in physicochemical compositions in hawthorn berries during the storage.** Table 1 summarises the changes in the compositions of hawthorn berries during storage at different temperatures. The water content of hawthorn berries decreased significantly over the whole storage period when stored at 25 °C. On the other hand, the moisture of hawthorn berries stored at 4 °C was stable during the first 60 day's storage, and a further increase of storage time to 180 days resulted in a significant loss of water. By contrast, the moisture of hawthorn berries stored at –18 °C was stable over the whole storage of 180 days.

During the storage, the hardness of hawthorn berries at 25 °C was stable for the first 15 days. Hawthorn berries stored at –18 °C had the lowest hardness at day 15, simply due to mechanical damage caused by the ice crystals formed in the freezing, which was irreversible after thawing (Luo et al. 2009b). Cold storage (4 °C) exhibited the best capacity in maintaining hardness, where no significant difference was observed within 60 days. A slight decrease from 1.3 kg·cm$^{-2}$ to 1.0 kg·cm$^{-2}$ occurred after storage for 180 days, which was related to the inhibition of water loss, respiration, as well as pectinase degradation under low temperatures (Khan et al. 2009).

The content of both total and reduced sugar decreased gradually during the storage period for all the hawthorn samples. The fastest reduction at the same storage time was observed in the group of 25 °C. The frozen hawthorn berries showed the slowest decline during storage. Similar results have been reported previously

Table 1. Effect of temperature difference on partial physicochemical indexes of hawthorn berries during the storage

| Time (days) | Moisture (%) | Hardness (kg·cm$^{-2}$) | Total sugar (%, DW) | Reducing sugar (%, DW) | Total acid (g.kg$^{-1}$, DW) | $L^*$ | $a^*$ | $b^*$ |
|---|---|---|---|---|---|---|---|---|
| 0 | 75.5 ± 0.1$^{b}$ | 1.3 ± 0.3$^{a}$ | 29.4 ± 0.1$^{a}$ | 26.7 ± 0.2$^{a}$ | 145.1 ± 0.0$^{a}$ | 38.3 ± 0.5$^{a}$ | 36.5 ± 0.4$^{a}$ | 22.1 ± 0.3$^{a}$ |
| 15$^{A}$ | 74.6 ± 0.2$^{e}$ | 1.3 ± 0.2$^{a}$ | 24.9 ± 0.1$^{c}$ | 22.9 ± 0.1$^{d}$ | 128.1 ± 0.7$^{f}$ | 36.5 ± 0.8$^{c}$ | 30.5 ± 0.3$^{c}$ | 18.2 ± 0.5$^{b}$ |
| 30$^{A}$ | 69.4 ± 0.1$^{h}$ | 0.8 ± 0.3$^{b}$ | 19.2 ± 0.2$^{f}$ | 17.2 ± 0.0$^{g}$ | 100.4 ± 0.0$^{h}$ | 34.6 ± 0.6$^{d}$ | 24.1 ± 0.3$^{e}$ | 13.0 ± 0.4$^{e}$ |
| 60$^{A}$ | 58.6 ± 0.0$^{j}$ | 0.8 ± 0.3$^{b}$ | 16.6 ± 0.1$^{h}$ | 14.6 ± 0.1$^{i}$ | 48.6 ± 0.5$^{i}$ | 31.1 ± 0.5$^{f}$ | 22.2 ± 0.1$^{f}$ | 11.4 ± 0.3$^{g}$ |
| 180$^{A}$ | NM | NM | NM | NM | NM | NM | NM | NM |
| 15$^{B}$ | 75.7 ± 0.1$^{a}$ | 1.4 ± 0.2$^{a}$ | 25.8 ± 0.1$^{b}$ | 24.8 ± 0.1$^{b}$ | 141.5 ± 0.6$^{c}$ | 38.0 ± 0.3$^{ab}$ | 31.2 ± 0.0$^{b}$ | 16.3 ± 0.5$^{c}$ |
| 30$^{B}$ | 74.8 ± 0.1$^{d}$ | 1.4 ± 0.2$^{a}$ | 22.7 ± 0.1$^{e}$ | 20.6 ± 0.1$^{e}$ | 129.4 ± 0.2$^{e}$ | 37.3 ± 0.6$^{b}$ | 30.3 ± 0.3$^{c}$ | 15.6 ± 0.4$^{d}$ |
| 60$^{B}$ | 73.7 ± 0.0$^{g}$ | 1.4 ± 0.2$^{a}$ | 18.7 ± 0.2$^{g}$ | 16.6 ± 0.4$^{h}$ | 108.9 ± 0.9$^{g}$ | 34.5 ± 0.3$^{d}$ | 28.8 ± 0.1$^{d}$ | 13.6 ± 0.3$^{e}$ |
| 180$^{B}$ | 59.2 ± 0.0$^{i}$ | 1.0 ± 0.1$^{c}$ | 14.8 ± 0.1$^{i}$ | 13.7 ± 0.1$^{j}$ | 44.9 ± 0.2$^{j}$ | 32.6 ± 0.3$^{e}$ | 14.4 ± 0.4$^{h}$ | 11.4 ± 0.2$^{g}$ |
| 15$^{C}$ | 75.1 ± 0.2$^{c}$ | 0.5 ± 0.1$^{d}$ | 29.5 ± 0.2$^{a}$ | 26.3 ± 0.2$^{a}$ | 143.2 ± 0.1$^{b}$ | 32.8 ± 0.6$^{e}$ | 22.8 ± 0.5$^{f}$ | 15.9 ± 0.8$^{cd}$ |
| 30$^{C}$ | 74.7 ± 0.1$^{de}$ | 0.5 ± 0.1$^{d}$ | 25.3 ± 0.1$^{b}$ | 23.4 ± 0.1$^{c}$ | 143.8 ± 0.2$^{b}$ | 32.2 ± 0.4$^{e}$ | 22.4 ± 0.2$^{f}$ | 15.5 ± 0.3$^{d}$ |
| 60$^{C}$ | 74.3 ± 0.1$^{f}$ | 0.4 ± 0.1$^{d}$ | 23.2 ± 0.3$^{d}$ | 22.1 ± 0.1$^{d}$ | 141.1 ± 0.0$^{c}$ | 32.4 ± 0.3$^{e}$ | 22.3 ± 0.3$^{f}$ | 15.4 ± 0.2$^{d}$ |
| 180$^{C}$ | 75.1 ± 0.1$^{c}$ | 0.4 ± 0.1$^{d}$ | 19.6 ± 0.1$^{f}$ | 18.3 ± 0.1$^{f}$ | 138.2 ± 0.0$^{d}$ | 29.4 ± 0.3$^{g}$ | 21.5 ± 0.3$^{g}$ | 13.0 ± 0.4$^{e}$ |

$^{a–j}$ significant differences between the means ($P < 0.05$); $^{A}$ 25 °C, $^{B}$ 4°C, $^{C}$ 18°C; NM – not measured, because the hawthorn fruit began to rot and lost its commodity value at this time; DW – dry weight; $L^*$ – lightness; $a^*$ – red/green value; $b^*$ – blue/yellow value

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(Cao et al. 2013), where it was found that the total soluble sugar content in pears gradually decreased during storage, and refrigerated pear fruits had less reduction than that unrefrigerated ones (Wang et al. 2020).

Citric acid, quinic acid, and malic acid are the main compounds of titratable acid in hawthorn berries (Liu et al. 2010). The change in total acid content during hawthorn storage was consistent with sugar content, which decreased with increasing storage time and in a sequence of –18 °C < 4 °C < 25 °C, indicating that low-temperature storage could effectively inhibit the degradation of total acid in hawthorn berries.

Lightness ($L^*$), red/green value ($a^*$), and blue/yellow value ($b^*$) of hawthorn berries stored at 25 °C and 4 °C gradually decreased during the storage, although they had different speeds. Hawthorn berries at 25 °C showed a faster decrease in colour within 60 days than at 4°C. When stored for 180 days, hawthorn berries at 4 °C had higher $L^*$ but lower $a^*$ and $b^*$ than those at –18 °C.

Figure 1 shows the visual changes of hawthorn berries during storage. When stored at 25 °C, rot spots appeared on the 30$^{th}$ day. Further extension of the storage time resulted in depressed skin, softened pulp tissue, and a browning colour. Cold storage (4 °C) showed a better protection effect on the hawthorn berries, where the rot spots were only noticed after storage for 60 days. The appearance of hawthorn berries at –18 °C did not change significantly during the storage period, but juice loss, pulp atrophy, and water loss occurred after 60 days of storage.

Figure 1 shows the visual changes of hawthorn berries during storage. When stored at 25 °C, rot spots appeared on the 30$^{th}$ day. Further extension of the storage time resulted in depressed skin, softened pulp tissue, and a browning colour. On the 180$^{th}$ day, the fruit was completely rotten and lost its commercial value. Cold storage (4 °C) showed a better protection effect on the hawthorn berries, where the rot spots were only noticed after storage for 60 days. These results are consistent with the study of Šamec and Piljac-Žegarac (2011), who found that hawthorn berries could be stored for longer days at 4 °C than those at 25 °C. The appearance of hawthorn berries at –18 °C did not change significantly during the storage period, but juice loss, pulp atrophy, and water loss occurred after 60 days of storage.

**Change of ascorbic acid content in hawthorn berries during the storage.** Figure 2 summarises the change in ascorbic acid content in hawthorn berries during storage. It is worth mentioning that no ascorbic acid was detected when the hawthorn berries were stored at 25 °C for 180 days, attributing to the severe rot of hawthorn berries. The ascorbic acid content at –18 °C showed the slowest decrease within 180 days, from 54.3 mg·(100 g)$^{-1}$ to 38.7 mg·(100 g)$^{-1}$ (d.b.), whereas the ascorbic acid content at 4 °C reduced by 64.4%, which indicated that low storage temperature was ef-

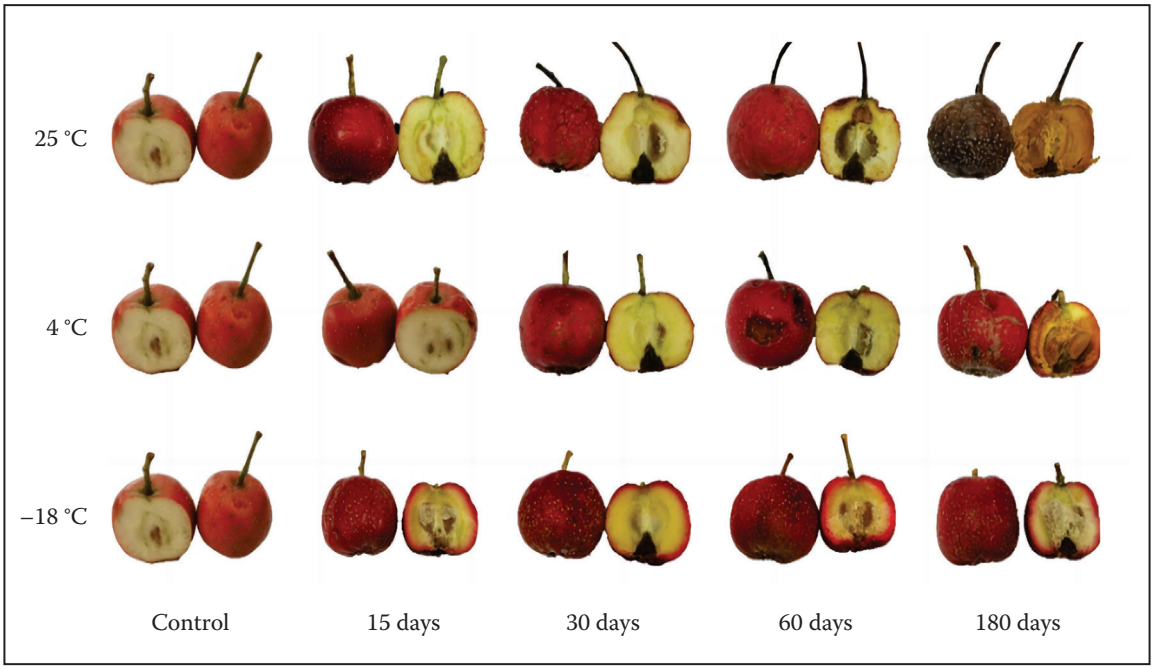


Figure 1. Visual changes of hawthorn berries during the storage

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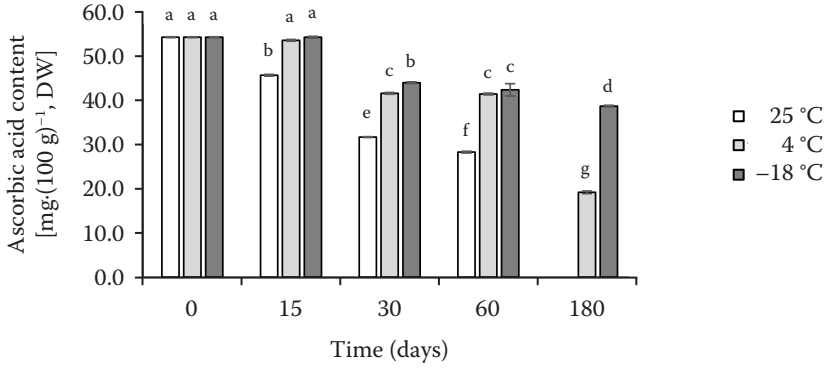


Figure 2. Change of ascorbic acid content in hawthorn berries during the storage

a–g – significant differences during each storage period ($P < 0.05$); DW – dry weight

fective in inhibiting the loss of ascorbic acid in hawthorn berries.

**Changes of phenolic profiles in hawthorn berries during the storage.** Figure 3 exhibits the changes in phenolic profiles during the storage of hawthorn berries. EPP content decreased gradually during the storage of hawthorn berries and showed the fastest rate in the group of 25 °C, followed by the group of 4 °C. On the other hand, no significant decrease in EPP value was noticed when stored at –18 °C ($P < 0.05$), indicating that the frozen storage temperature could maintain the stability of EPP in hawthorn berries. Chang et al. (2006) also verified that a lower storage temperature is more conducive to stabilising the EPP content and activity of phenolic substances in hawthorn fruits.

The storage temperature showed a different effect on the HPP content of hawthorn berries. No significant difference was observed in the hawthorn samples

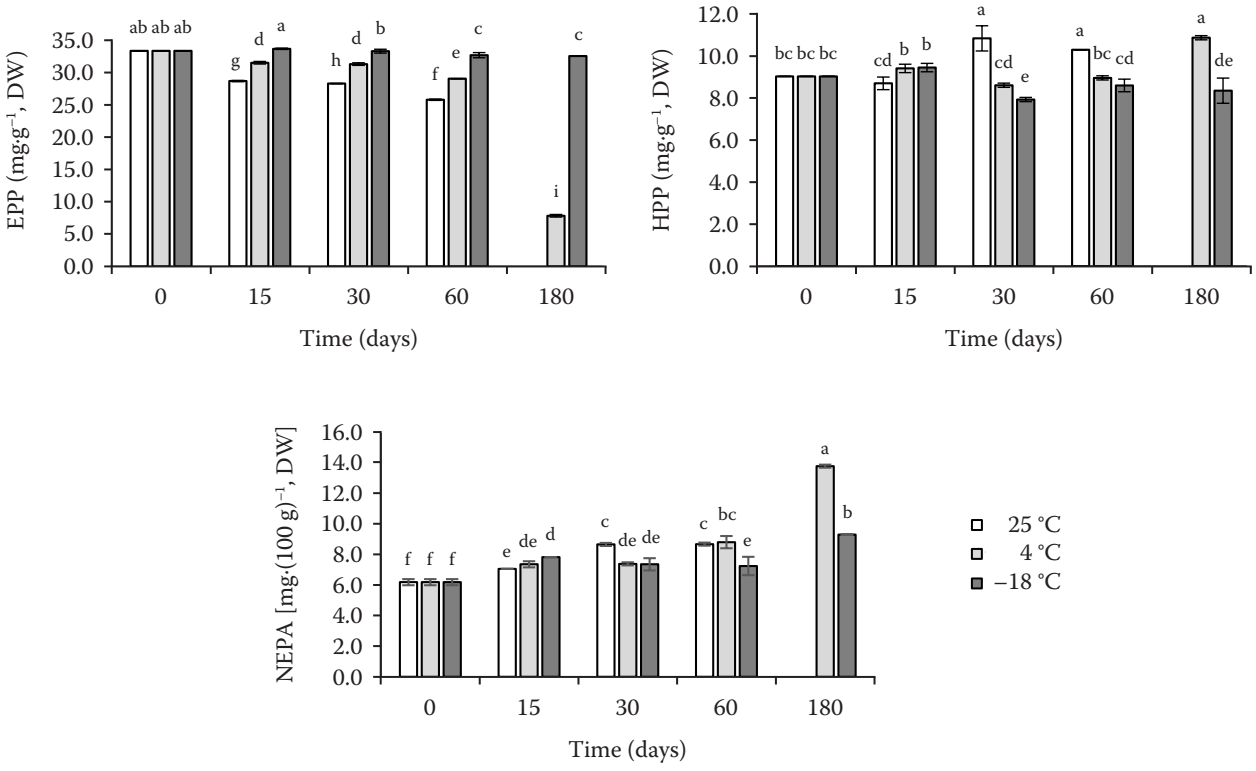


Figure 3. Changes of phenolic profiles in hawthorn berries during the storage

a–i – significant differences during each storage period ($P < 0.05$); DW – dry weight; EPP – extractable polyphenol; HPP – hydrolysable polyphenol; NEPA – non-extractable proanthocyanidins

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stored at different temperatures during the first 15 days. While the HPP content in the group of –18 °C was relatively stable throughout the whole storage period, a further increase of the storage time to 30 days led to a significant increase of HPP content in the group of 25 °C, which remained stable. On the other hand, the HPP content in the group of 4 °C was relatively stable within 60 days of storage but increased significantly on the 180$^{th}$ day. The NEPA content in hawthorn berries stored at different temperatures increased significantly within 15 days. At 25 °C, the NEPA value continued to increase at 30 days and then stabilised. On the contrary, no further increase of NEPA content in the groups of 4 °C and –18 °C was noticed during the storage of 15–60 days. At 180 days, the NEPA content of both groups increased significantly. A similar change trend of proanthocyanidins content has been reported during the storage of cherry, blackberry, and red grape (Nemzer et al. 2018). However, Chang et al. (2006) found that the content of proanthocyanidins B2 in hawthorn decreased by more than 50% at 4 °C after 6 months, probably due to the variety and origin.

**Change of total flavonoid content in hawthorn berries during storage.** As shown in Figure 4, the total flavonoid content in hawthorn samples decreased gradually during storage. The fastest reduction happened at the highest storage temperature of 25 °C, followed by the group of 4 °C. The hawthorn berries stored at –18 °C exhibited the slowest change of total flavonoid content, which remained high value even at the longest storage time of 180 days. Similar results were described from hawthorn and cornelian cherries by Šamec and Piljac-Žegarac (2011). All these above results indicated that reducing the storage temperature of hawthorn berries was beneficial to improve flavonoid stability, which may further affect the stability of the antioxidant capacity of hawthorn berries.

**Changes of antioxidant capacities in hawthorn berries during the storage.** As presented in Table 2, FRAP of EPP and HPP in the group of 25 °C showed the minimum value on the 30$^{th}$ and 15$^{th}$ day, respectively. Interestingly, the half maximal inhibitory concentration $IC_{50}$ of DPPH-RSC peaked at the same point, indicating the lowest antioxidant capacities of EPP and HPP (the higher the value of $IC_{50}$, the weaker the antioxidant capacity). However, the stable antioxidant capacities of HPP were consistent with the change in EPP content (Figures 1–3). The changes in antioxidant capacity and the content of NEPA in the group of 25 °C also agreed with each other.

The changes of FRAP and DPPH-RSC of EPP and HPP in the group of 4 °C were not significant within 60 days of storage. Whereafter, both FRAP and DPPH-RSC of EPP decreased significantly on the 180$^{th}$ day while FRAP and DPPH-RSC of HPP increased significantly, which corresponded with the changes of EPP and HPP content in hawthorn berries (Figures 2–3). EPP, HPP, and NEPA in the group of –18 °C were relatively stable during the whole storage, which confirmed that reducing the storage temperature of hawthorn berries could significantly maintain the antioxidant capacities of phenolic compounds (Mu et al. 2021).

**Changes of polyphenolic oxidase and peroxidase activities in hawthorn berries during the storage.** According to the present results, significant differences were observed in moisture, reducing sugar, total sugar, TA, and ascorbic acid of hawthorn berries stored at different storage temperatures. Hawthorn berries can be stored for 30 and 60 days at 25 °C and 4 °C, respectively. Although hawthorn berries stored

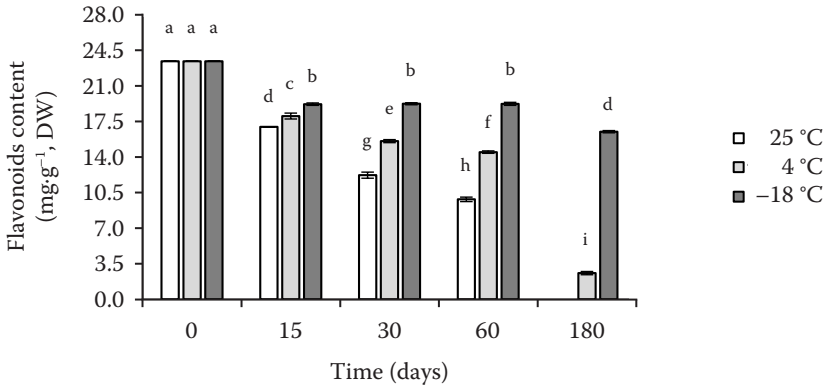


Figure 4. Change of total flavonoids content in hawthorn berries during the storage

a–i – significant differences during each storage period ($P < 0.05$); DW – dry weight

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Table 2. Changes of antioxidant capacities in hawthorn berries during the storage

| Time (days) | FRAP (mmol·L$^{-1}$) | | DPPH-RSC ($IC_{50}$, mg) | | |
|---|---|---|---|---|---|
| | EPP | HPP | EPP | HPP | NEPA |
| 0 | 15.36 ± 0.08$^{bc}$ | 0.40 ± 0.00$^{bc}$ | 9.65 ± 0.30$^{d}$ | 2.14 ± 0.10$^{e}$ | 9.65 ± 0.04$^{cd}$ |
| 15$^{A}$ | 13.56 ± 0.24$^{de}$ | 0.32 ± 0.05$^{f}$ | 8.88 ± 0.09$^{ef}$ | 3.49 ± 0.12$^{a}$ | 9.50 ± 0.16$^{cde}$ |
| 30$^{A}$ | 11.44 ± 0.08$^{f}$ | 0.39 ± 0.02$^{bcd}$ | 10.43 ± 0.04$^{bc}$ | 2.53 ± 0.18$^{bc}$ | 7.81 ± 0.2$^{g}$ |
| 60$^{A}$ | 16.46 ± 0.09$^{a}$ | 0.43 ± 0.01$^{b}$ | 8.45 ± 0.32$^{f}$ | 2.60 ± 0.06$^{bc}$ | 8.38 ± 0.69$^{fg}$ |
| 180$^{A}$ | NM | NM | NM | NM | NM |
| 15$^{B}$ | 13.91 ± 0.27$^{d}$ | 0.37 ± 0.01$^{bcde}$ | 9.37 ± 0.01$^{de}$ | 2.26 ± 0.05$^{de}$ | 9.52 ± 0.01$^{cde}$ |
| 30$^{B}$ | 13.99 ± 0.03$^{d}$ | 0.33 ± 0.01$^{cdef}$ | 8.67 ± 0.10$^{ef}$ | 2.73 ± 0.$^{05b}$ | 7.25 ± 0.17$^{g}$ |
| 60$^{B}$ | 13.32 ± 0.21$^{e}$ | 0.37 ± 0.06$^{bcde}$ | 10.47 ± 0.11$^{b}$ | 2.71 ± 0.18$^{b}$ | 8.90 ± 0.02$^{e}$ |
| 180$^{B}$ | 3.61 ± 0.54$^{g}$ | 0.59 ± 0.01$^{a}$ | 20.81 ± 0.69$^{a}$ | 1.64 ± 0.19$^{f}$ | 11.84 ± 0.06$^{a}$ |
| 15$^{C}$ | 15.83 ± 0.08$^{b}$ | 0.39 ± 0.01$^{bcd}$ | 8.85 ± 0.09$^{ef}$ | 2.21 ± 0.03$^{de}$ | 9.66 ± 0.15$^{cd}$ |
| 30$^{C}$ | 15.65 ± 0.53$^{bc}$ | 0.41 ± 0.05$^{b}$ | 9.03 ± 0.13$^{de}$ | 2.21 ± 0.06$^{de}$ | 9.12 ± 0.03$^{de}$ |
| 60$^{C}$ | 15.32 ± 0.05$^{c}$ | 0.32 ± 0.00$^{ef}$ | 9.82 ± 0.49$^{cd}$ | 2.30 ± 0.04$^{cd}$ | 9.89 ± 0.32$^{c}$ |
| 180$^{C}$ | 15.41 ± 0.03$^{bc}$ | 0.33 ± 0.06$^{f}$ | 9.82 ± 0.07$^{bcd}$ | 2.29 ± 0.17$^{cde}$ | 9.88 ± 0.07$^{c}$ |

$^{a–j}$ significant differences between the means ($P < 0.05$); $^{A}$ 25 °C, $^{B}$ 4 °C, $^{C}$ 18 °C; NM – not measured, because the hawthorn fruit began to rot and lost its commodity value at this time; FRAP – ferric reducing antioxidant power; DPPH-RSC – 2,2-diphenyl-1-picrylhydrazyl radical scavenging capacity; $IC_{50}$ – half maximal inhibitory concentration; EPP – extractable polyphenol; HPP – hydrolysable polyphenol; NEPA – non-extractable proanthocyanidins

at –18 °C possessed more sugar and organic acid, their textural characteristics were negatively affected. The content of EPP and flavonoids, PPO and POD activities decreased significantly during storage, while NEPA content increased slowly. In conclusion, reducing the storage temperature of hawthorn berries was beneficial to improving the nutritional and functional stability and PPO and POD activities. However, considering the storage cost and processing convenience, these different storage methods can be adopted flexibly to ensure the stability of hawthorn quality and extend the supply cycle and the specific storage conditions and their impact on hawthorn quality need to be further studied.

## CONCLUSION

According to the present results, significant differences were observed in moisture, reducing sugar, total sugar, TA, and ascorbic acid of hawthorn ber-

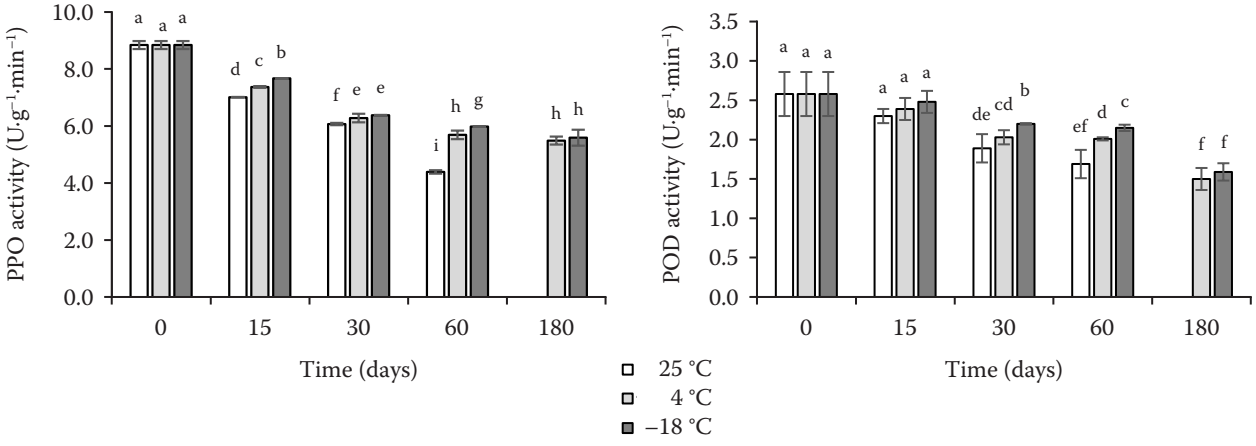


Figure 5. Changes of polyphenolic oxidase and peroxidase activities in hawthorn berries during the storage

a–i – significant differences during each storage period ($P < 0.05$); PPO – polyphenolic oxidase; POD – peroxidase

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ries stored at different temperatures. Hawthorn berries can be stored for 30 and 60 days at 25 °C and 4 °C respectively. Although hawthorn berries stored at –18 °C possessed more sugar and organic acid, their textural characteristics were negatively affected. The content of EPP and flavonoids, PPO, and POD activities decreased significantly during storage, while NEPA content increased slowly. In conclusion, reducing the storage temperature of hawthorn berries was beneficial to improving the nutritional and functional stability and PPO and POD activities. However, considering the storage cost and processing convenience, these different storage methods can be adopted flexibly to ensure the stability of hawthorn quality and extend the supply cycle and the specific storage conditions and their impact on hawthorn quality need to be further studied.

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Received: July 15, 2023
Accepted: November 10, 2023
Published online: November 21, 2023