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Effect of Leaf Extract from *Lycium barbarum* on Preservation of Cherry Tomato Fruit

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Abstract: The preservation of cherry tomatoes is a challenge for farmers, sellers, and processors. In recent years, natural extracts of plants have been increasingly used for the preservation of fruits and vegetables. In this study, we investigated the effect of treatment with goji berry (*Lycium barbarum*) leaf extract on the postharvest freshness of cherry tomatoes, and we determined the active ingredients, antioxidant capacity, and antifungal activity of the extract. Goji leaf extracts were tested at different concentrations (0.2–1.0 g/L) to assess their effects on preserving the freshness of cherry tomatoes at 5 °C and 20 °C. The goji berry leaf extract was rich in polysaccharides, saponins, polyphenols, and other active ingredients (1.11–45.83 mg/g), and the antioxidant capacity and antifungal activity were outstanding. Treatments with 0.2, 0.4, and 0.6 g/L of goji berry leaf extract at 20 °C helped to preserve tomato fruit, where 0.4 g/L was the most effective, followed by 0.2 and 0.6 g/L. However, 0.8 and 1.0 g/L had no effect. Treatment with 1.0 g/L of goji berry leaf extract at 5 °C effectively reduced the loss of quality of tomato fruit. This treatment maintained the firmness and color of the tomatoes and maintained the levels of nutrients such as vitamin C, total acids, and total soluble solids. The next most effective doses were 0.8 g/L and 0.6 g/L. Cherry tomatoes treated with goji berry leaf extract could be stored for 21 days at 20 °C and for 35 days at 5 °C. Compared with the control groups treated with distilled water and no treatment, the storage period was extended by 3–6 days at 20 °C and by 7–14 days at 5 °C. The results obtained in this study provide a theoretical basis for extending the storage period of cherry tomatoes using goji berry leaf extract and the development of natural preservatives as well as enhancing the utilization of germplasm resources.

Keywords: cherry tomato; shelf life; *Lycium barbarum* leaf; natural preservatives; post-harvest preservation

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1. Introduction

Cherry tomatoes, which are native to South America, are the most primitive tomato variety. The diameter of a cherry tomato ranges from 1.5 to 3.0 cm [1]. Cherry tomatoes are one of the "Four Fruits" prioritized by the Food and Agriculture Organization of the United Nations. The cherry tomato (*Solanum lycopersicum*) is a member of the Solanaceae family that is in high demand among customers because of its delicious taste, nutritional content, and attractive appearance [2]. Compared with larger tomatoes, studies have shown that cherry tomatoes are more productive and that they contain higher quantities of nutritionally and functionally significant bioactive substances (e.g. lycopene, β-carotene, the colorless carotenoid phytoene, chlorogenic acid, quercetin, vitamin C, and tocopherols) [3,4]. However, cherry tomatoes are respiratory climacteric fruits characterized by the commencement of senescence at the end of their development, where physiological activities and other metabolic processes related to product degradation are intensified [5,6]. Furthermore, fruit degradation and decay occur readily after harvesting due to microbial infection and external mechanical action, which can greatly limit the shelf life, thereby increasing the difficultly of storing and preserving fresh cherry tomatoes in transit [7–9].

The most widespread methods used for storing and preserving cherry tomatoes are low temperature storage, chemical preservative treatment, irradiation, and modified atmo-

sphere storage [10–13]. Cold damage makes it difficult to use lower storage temperatures to control disease and extend the storage period of tomatoes. Modified atmosphere gas storage is effective for preserving cherry tomatoes, but it is also expensive and time-consuming. Using chemical and synthetic preservatives can extend the storage period to some extent, but preservatives always have an associated risk of short- and long-term side effects. At present, food storage and preservation research is increasingly focusing on non-toxic, efficient, and cost-effective natural food preservation agents derived from plants and animals, which are characterized by high dispersibility, moisture retention, antibacterial capabilities, and other benefits [14,15]. There have been some encouraging reports on the use of natural preservatives to increase the shelf life of vegetables and other food products. *Osmunda japonica* (Thunb) polysaccharides could effectively reduce water loss and bacterial pollution in tomatoes during storage, and they had a good preservation effect [16]. Supercritical impregnation of olive leaf extract had some anti-microbial ability and could extend the shelf life of cherry tomatoes by 20 days [15]. Additionally, a turmeric solution had some antibacterial effects and could prevent postharvest loss of tomatoes [14].

The goji berry (*Lycium barbarum* L.) is a perennial woody plant in the Solanaceae family found mostly in temperate subtropical areas of North America, Eurasia, southern Africa, and Australia [17–19]. Goji berry fruit has been used for over 2000 years as a traditional Chinese medicinal substance or health food, and the fruit is highly popular in Chinese cuisine as an ingredient in soup or rice porridge [20–22]. Goji berry leaves are used as tea, medicinal vegetables, and herbal drugs in China. Extracts from goji berry leaves have been shown to exhibit antibacterial, antioxidant, and anti-diabetic activities. Goji berry leaves also contain polysaccharides and flavonoids, and their excellent antioxidant activities have been demonstrated based on the scavenging of superoxide and 2,2-diphenyl-1-picrylhydrazyl (DPPH) [23,24]. In the present study, we investigated whether goji berry leaf extract could preserve the freshness of cherry tomato fruit at 5 °C and 20 °C in order to increase the utilization of high-value resources in the Goji berry industry, and we provided a theoretical basis for the post-harvest preservation of cherry tomatoes and the development of goji berry leaf as a natural preservative.

2. Materials and Methods

2.1. Plant Material

Cherry tomato "Bijiao" fruits with a diameter of 1–3 cm were obtained in Xujiazhuang (annual average temperature: 10 °C; altitude: 1105 m; annual precipitation: 200.5 mm), Yinchuan, Ningxia during May 2019. The fruits were picked at the hard red stage, and they were devoid of pests and diseases and had uniform fruit size, firmness, and color. They were promptly transported to the laboratory for testing. In May 2019, goji berry leaves (Zhongning No. 7) were collected in Zhongning County, Ningxia, China. The goji berry leaves were cleaned and stored at −80 °C for 48 h before drying in a vacuum freeze drier for 48 h. Samples were then crushed and sieved through a 0.18 mm sieve to generate sample particles with a size between 0.1 mm and 0.18 mm. They were then stored at 25 °C away from light.

2.2. Active Substance Contents

The total phenolic content was determined using the Folin–Ciocalteu method [25]. The total flavonoid content was determined using the $NaNO_2$–$AlCl_3$ method [26]. The total flavanol content was determined using the vanillin colorimetric method [27]. The saponin content was determined using the vanillin–glacial acetic acid method [28]. The polysaccharide content was determined using the phenol–sulfuric acid method [29]. The alkaloid content was determined using the bromocresol green colorimetric method [30].

2.3. Determination of Freshness Indicators for Cherry Tomatoes

The following seven treatments were tested in this study: no treatment control (CK), distilled water treatment control (CKW), and goji berry leaf extract at doses of 0.2, 0.4,

0.6, 0.8, and 1.0 g/L. Cherry tomatoes were soaked in goji berry leaf extract or distilled water for 3 min, with 10 tomatoes replicated three times for each treatment. After drying, the tomatoes were placed into disposable lunch boxes and stored at 5 °C (measured by sampling every seven days) or 20 °C (measured by sampling every three days) until the tomato fruits exhibited signs of degradation.

The weight of a cherry tomato was regarded as the initial weight (Wi) before packing in each container. The weight of each cherry tomato was recorded and labeled as Wt during storage. Thus, Wi–Wt was calculated as the weight lost by a cherry tomato during storage [31]. The chromaticity was measured for tomatoes using a CR-200 colorimeter [32].

Firmness was measured on two opposite sides at a maximum distance for each tomato using a durometer (SHT Tools Co., Ltd., Shanghai, China) [33]. The total soluble solids (TSS) content of cherry tomatoes were determined with a digital glucometer (Alto PAL-3 Digital Glucometer, Tokyo, Japan) at ambient temperature [12]. The titratable acid (TA) content were determined by diluting 10 mL of tomato juice to 100 mL with distilled water in a volumetric flask, allowing it to stand for 30 min, and filtering; 20 mL of the solution was adjusted to pH 8.1 with 0.1 mol/L of NaOH [34]. Superoxide dismutase (SOD) enzyme activity was determined using the nitro blue tetrazolium photoreduction technique [35]. The vitamin C content was determined using the 2,6-dichloroindophenol titrimetric method [16]. The analysis was performed in triplicate regarding the freshness index of cherry tomatoes.

2.4. Antioxidant Activity Assay

The DPPH radical scavenging activity assay was performed as described by Taiwo et al. [36]. The capacity to reduce copper ions was tested using the method described by Kondakci et al. [37].

2.5. Antifungal Capacity Assay

The capacity to inhibit fungi was evaluated using the turbidimetric technique [38,39], where the concentration of the fungal suspension (*Penicillium* sp.) was adjusted to an absorbance value of around 1 at 600 nm (OD_{600} = 1.0). Goji berry leaf extract was weighed at 0.1 g and diluted in 100 mL of distilled water to obtain a 1 mg/mL solution before passing it through a 0.22 μm filter. Next, 20 mL of potato dextrose broth liquid medium, 0.1 mL of fungal suspension, and 0.5 mL of goji berry leaf extract were combined in a 50 mL conical flask before incubating for 48 h at 28 °C in a constant temperature incubator. The absorbance was then measured at 600 nm. After measuring the absorbance, 0.1 mL of each culture solution was aspirated and transferred to potato dextrose agar solid medium before incubating at a constant temperature of 28 °C for 48 h. Colony growth status was then evaluated. Three replicates were included.

2.6. Statistical Analyses

Analyses of all indicators were replicated three times. All data were expressed as the mean ± standard error. SPSS version 26.0 (SPSS Inc. Chicago, IL, USA) was used to detect significant differences in the experimental results. Experimental differences were determined using a one-way analysis of variance (ANOVA) and Duncan test at 0.05 levels. Graphs were plotted using Origin 2021b.

3. Results

3.1. Contents of Active Substances in Lycium barbarum Leaf Extract

Several phenols, polysaccharides, flavonoids, aromatic acids, and terpenoids were detected in *Lycium barbarum* leaves in previous phytochemical studies [40–43]. As shown in Figure 1, the contents of active substances in *Lycium barbarum* leaves comprised total phenols, saponins, total flavonoids, alkaloids, total flavanols, and polysaccharides. The total phenol (45.83 mg/g) and total flavonoid (42.19 mg/g) contents were relatively high and were 38.0–41.3 times higher than those of the other active ingredients. The polysaccharide

content (1.11 mg/g) was lowest. The phenol and total flavonoid contents of *Lycium chinense* leaves were positively correlated with antioxidant activities in a previous study [44], which was possibly due to the higher total phenol and flavonoid contents.

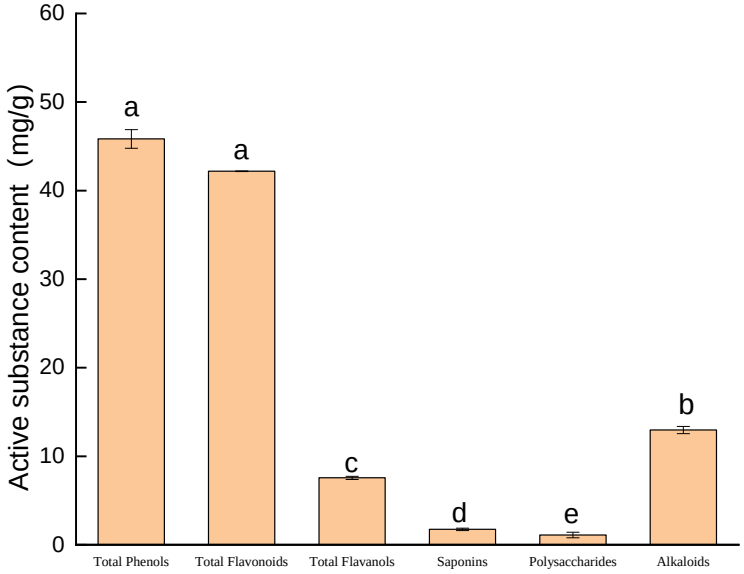


Figure 1. Active substances in *Lycium barbarum* leaf extract. Different lowercase letters indicate significant differences ($p < 0.05$).

3.2. Antioxidant Capacity and Antifungal Activity of Lycium barbarum Leaf Extract

Table 1 shows that the *Lycium barbarum* leaf extract exhibited antioxidant activities; the DPPH radical scavenging activity was 8.07 μmol/g, and the copper ion reducing activity was 2.54 μmol/g with a leaf extract concentration of 1.0 g/L. The OD_{600} value was positively correlated with the amount of fungi, where a greater number of fungi were present in the culture when the OD_{600} value was larger. This value was used to assess the antifungal activity. Compared with control and distilled water, *Lycium barbarum* leaf extract showed better inhibition of fungi (Figure 2). As shown in Table 2, the *Lycium barbarum* leaf extract at a concentration of 1.0 g/L significantly inhibited *Penicillium* sp.

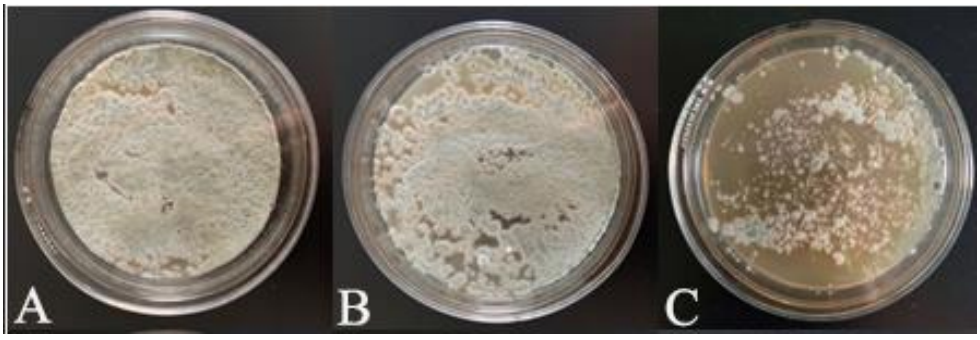


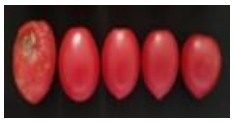
Figure 2. Inhibitory effects of different treatments on *Penicillium*. Note: (**A**) represents *Penicillium* growth as a control. (**B**,**C**) show the suppression of *Penicillium* by distilled water and *Lycium barbarum* leaf extract, respectively.

Table 1. Antifungal activity of *Lycium barbarum* leaf extract.

Culture Solution	Absorption Value, OD_{600}
Penicillium	0.90 ± 0.02 a
Penicillium + distilled water	0.84 ± 0.01 b
Penicillium + *Lycium barbarum* leaf extract	0.48 ± 0.01 c

Different lowercase letters indicate significant differences ($p < 0.05$).

Table 2. Changes in cherry tomato color under different treatments (20 °C).

Days	Treated with Distilled Water	No Treatment	Treated with 0.4 g/L Extract Solution
0			
3			
6			
9			
12			
15			
18			
21			

3.3. Effects of Different Lycium barbarum Leaf Extract Concentrations on Weight Loss by Cherry Tomatoes

Studies have shown that weight loss by tomatoes increases with storage time. Weight loss is mainly due to the loss of water by transpiration and the loss of carbon reserves. Increased weight loss may be associated with transpiration through microscopic cracks on the fruit surface [45,46]. There were significant differences ($p < 0.05$) in the effect of different concentrations of *Lycium barbarum* leaf extract on the rate of tomato fruit mass loss at different ambient temperatures (20 °C and 5 °C). At different ambient temperatures (20 °C and 5 °C), we found that weight loss increased with storage time. During the storage period at 20 °C, the weight losses by cherry tomatoes under different *Lycium barbarum* leaf extract concentrations followed the order of: 0.4 g/L < 0.2 g/L < 0.6 g/L < 0.8 g/L < 1.0 g/L (Figure 3A). Thus, excessively low or high *Lycium barbarum* leaf extract concentrations accelerated weight loss and reduced the effectiveness of fruit preservation. However, weight loss decreased as the extract concentration increased at 5 °C. During the storage process at 5 °C, the weight losses under different *Lycium barbarum* leaf extract concentrations followed the order of: 1.0 g/L < 0.8 g/L < 0.6 g/L < 0.4 g/L < 0.2 g/L. Thus, the weight loss at 5 °C was lower when the *Lycium barbarum* leaf extract concentration was greater, and the preservation of cherry tomatoes was better (Figure 3B). At 5 °C and 20 °C, the weight

loss of every sample treated with different concentration of *Lycium barbarum* leaf extract was found to be lower than that of the untreated group which was kept as control.

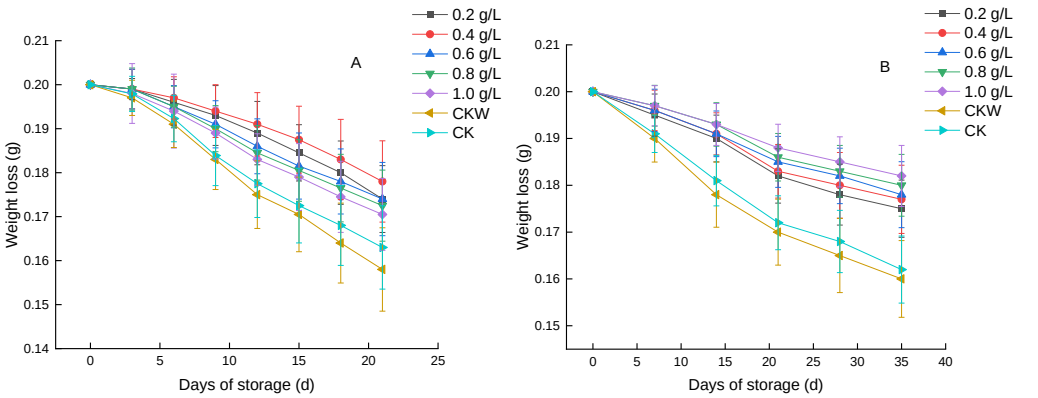


Figure 3. Effects of different *Lycium barbarum* leaf extract concentrations on weight loss by cherry tomatoes during storage at 20 °C (**A**) and 5 °C (**B**).

3.4. Effects of Different Lycium barbarum Leaf Extract Concentrations on the Brightness (L) of Cherry Tomatoes

Under each *Lycium barbarum* leaf extract concentration treatment at 20 °C and 5 °C, the L values for cherry tomatoes decreased continually with the storage period. The decreases in the L values at 20 °C were greater under the 0.8 g/L and 1.0 g/L *Lycium barbarum* leaf extract treatments compared with CK, and the decreases in the L values for the other treatments followed the order of: 0.4 g/L < 0.2 g/L < 0.6 g/L. Thus, the lower *Lycium barbarum* leaf extract concentrations were more effective than the higher concentrations at 20 °C, and the epidermal brightness of cherry tomatoes was maintained better at the lower concentration. This again indicates that the preservation of freshness was greater under these conditions (Figure 4A). At 5 °C, the L values for the cherry tomatoes decreased continually under each concentration as the storage time increased, and the decreases were lower than those under CK and CKW. The decrease in L value in the 1.0 g/L concentration group was significantly lower than that in the other concentration groups ($p < 0.05$). During the storage process at 5 °C, the decreases in the L values followed the order of: 1.0 g/L < 0.8 g/L < 0.6 g/L < 0.4 g/L < 0.2 g/L. Thus, at 5 °C, higher *Lycium barbarum* leaf extract concentrations reduced the decrease in the brightness values for cherry tomatoes, thus indicating a greater preservation effect (Figure 4B). In all cases, L values decreased over time. A reduction in L values during storage of tomatoes was also observed by other authors, representing a darkening of fruit associated with maturity [47].

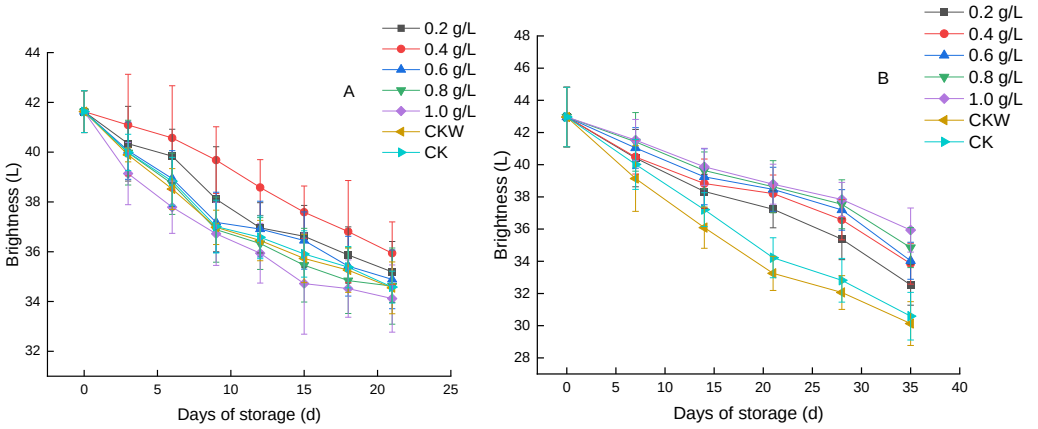


Figure 4. Effects of different *Lycium barbarum* leaf extract concentrations on the brightness (L) of cherry tomatoes at 20 °C (**A**) and 5 °C (**B**).

3.5. Effects of Different Lycium barbarum Leaf Extract Concentrations on the Firmness of Cherry Tomatoes

Firmness is an important indicator used to estimate fruit maturity [48]. The firmness of the cherry tomatoes decreased with storage time under all treatments. The firmness of the tomatoes stored at room temperature was similar to that reported by Pinheiro and Wu [49,50]. The firmness values were considerably higher for tomato fruits treated with *Lycium barbarum* leaf extract at concentrations of 0.2, 0.4, and 0.6 g/L compared with CK throughout the storage period. The 0.4 g/L treatment was the most effective concentration. After 21 days of storage at 20 °C, the firmness values were lower for tomato fruits treated with *Lycium barbarum* leaf extract at 0.8 g/L and 1.0 g/L compared with CK, thereby demonstrating that an excessively high *Lycium barbarum* leaf extract concentration effectively suppressed the decrease in tomato fruit firmness (Figure 5A). As shown in Figure 5B, the changes in tomato fruit firmness under each treatment as storage time increased were similar at 5 °C to those at 20 °C; fruit firmness differed significantly ($p < 0.05$) between each treatment and CK throughout the storage period, and the firmness values followed the order of: 1.0 g/L > 0.8 g/L > 0.6 g/L > 0.4 g/L > 0.2 g/L. Thus, at 5 °C, the firmness of cherry tomatoes declined more slowly, and greater freshness was retained when the *Lycium barbarum* leaf extract concentration was higher. For the same storage time, the firmness of the tomatoes stored at 5 °C was preserved more than that at 20 °C. This was due to enzymatic inhibition caused by low temperatures, as enzymes like pectinesterase and polygalacturonase soften the fruit structure [51].

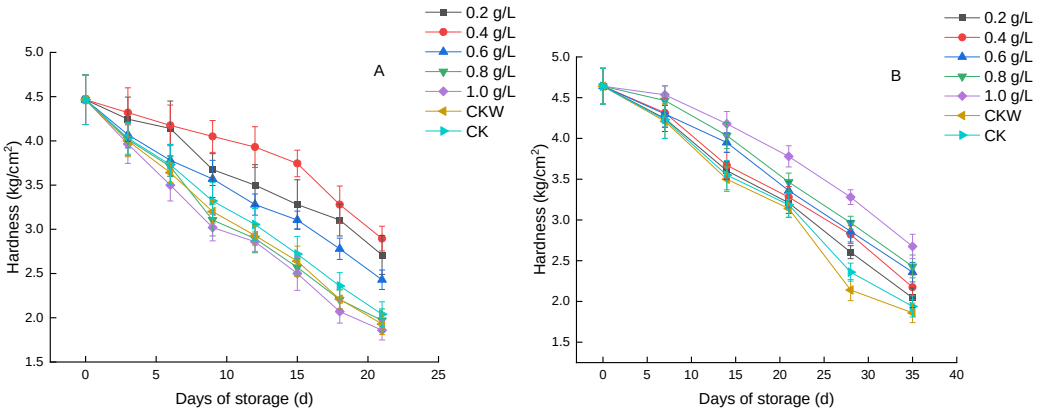


Figure 5. Effects of different *Lycium barbarum* leaf extract concentrations on the firmness of cherry tomatoes at 20 °C (**A**) and 5 °C (**B**).

3.6. Effects of Different Lycium barbarum Leaf Extract Concentrations on the Chromaticity (a/b) of Cherry Tomatoes

The deterioration of tomatoes is a consequence of biochemical changes that affect the color (chromaticity) and textural properties. The chromaticity value ranges from green to red, where positive values are red and negative values are green. The a/b value is utilized to represent the shift in fruit color, where the b value ranges from blue to yellow and the yellow color is brighter when the b value is higher [52]. The chromaticity (a/b) increased for cherry tomatoes treated with different *Lycium barbarum* leaf extract concentrations as storage duration increased at 20 °C (Figure 6A). The coloration (a/b) was significantly lower for tomatoes treated with *Lycium barbarum* leaf extract at concentrations of 0.2, 0.4, and 0.6 g/L compared with CK throughout the storage period ($p < 0.05$). Thus, the different concentrations of *Lycium barbarum* leaf extract delayed the change in the color of tomatoes, and 0.4 g/L had the greatest effect. After storage for 21 days, the coloration (a/b) was higher for tomato fruits treated with concentrations of 0.8 g/L and 1.0 g/L compared with CK. Thus, high concentrations of *Lycium barbarum* leaf extract were effective at preserving tomatoes. Furthermore, Table 3 shows that tomatoes treated with CKW decayed after 18 days, whereas tomatoes treated with 0.4 g/L of *Lycium barbarum* leaf extract did not

decay after 21 days. Thus, the *Lycium barbarum* leaf extract effectively extended the tomato preservation period. During storage at 5 °C, the chromaticity (a/b) of tomatoes was significantly lower under each *Lycium barbarum* leaf extract treatment compared with CK (Figure 6B). Thus, different *Lycium barbarum* leaf extract concentrations could delay the change in the chromaticity (a/b) of tomatoes, and 1.0 g/L was the most effective at preserving their freshness at 20 °C. Tomatoes exhibited considerable degradation and withering after storage for 28 days under CKW and CK conditions, as shown in Table 3 By contrast, tomatoes treated with *Lycium barbarum* leaf extract at 1.0 g/L did not rot and they retained their color after storage for 35 days. Chromaticity changes are an important indicator of shelf life and maturity of cherry tomatoes and are related to the concentration of lycopene. The range of chromaticity values of cherry tomatoes treated with *Lycium barbarum* leaf extract was consistent with the study of Won et al. [52,53].

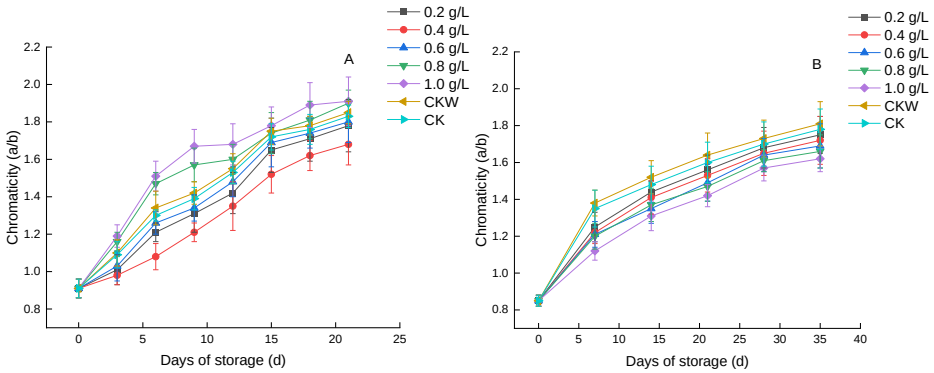


Figure 6. Effect of different *Lycium barbarum* leaf extract concentrations on the chromaticity (a/b) of cherry tomatoes at 20 °C (**A**) and 5 °C (**B**).

Table 3. Changes in color of cherry tomatoes under different treatments (5 °C).

Days	Treated with Distilled Water	No Treatment	Treated with 1.0 g/L Extract Solution
0			
7			
14			
21			
28			
35			

3.7. Effects of Different Lycium barbarum Leaf Extract Concentrations on the Vitamin C Content of Cherry Tomato

The effect of different concentrations of *Lycium barbarum* leaf extract on the vitamin C content of cherry tomato fruits at different ambient temperatures was significantly different ($p < 0.05$). Figure 7 shows that the vitamin C content of cherry tomatoes increased and then decreased during storage, and treatment with *Lycium barbarum* leaf extract inhibited the reduction in vitamin C content to varying degrees. The cherry tomatoes were not fully mature, and they underwent a post-ripening process in the early stage of storage, which is why the vitamin C content initially increased. Thus, a peak in the vitamin C content of the tomatoes occurred before a downward trend (Figure 7A), as was also shown by Liu et al. [16]. The first peak in vitamin C content of 32.09 mg/g occurred after storage for seven days and the second peak of 35.95 mg/g was found after treatment with *Lycium barbarum* leaf extract at 0.4 g/L after storage for nine days. The different *Lycium barbarum* leaf extract concentrations had different effects on delaying the loss of vitamin C from tomatoes, and 0.4 g/L was the most effective. After storage for up to 21 days, the vitamin C content of tomatoes was lower under treatment with *Lycium barbarum* leaf extract at 0.8 g/L and 1.0 g/L compared with CK (Figure 7B). Thus, high concentrations of *Lycium barbarum* leaf extract were not effective at maintaining the vitamin C content of tomatoes.

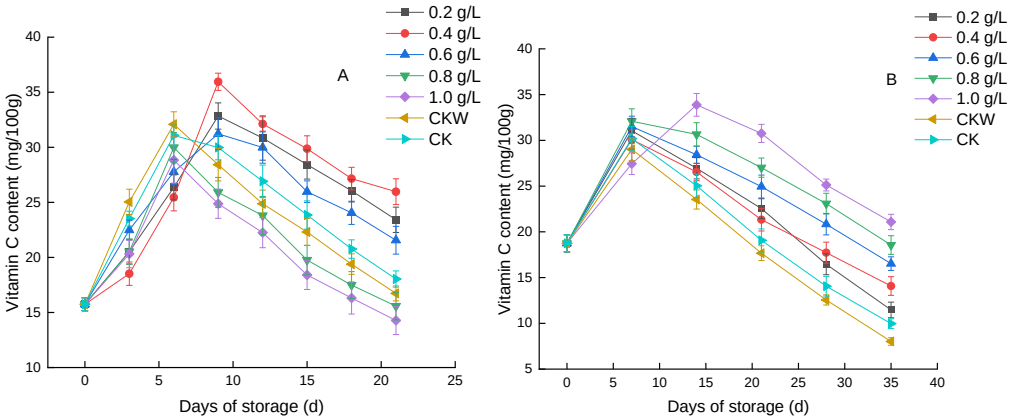


Figure 7. Effects of different *Lycium barbarum* leaf extract concentrations on the vitamin C content of cherry tomatoes at 20 °C (**A**) and 5 °C (**B**).

3.8. Effect of Different Lycium barbarum Leaf Extract Concentrations on SOD Enzyme Activities of Cherry Tomato

Superoxide dismutase (SOD) is a key antioxidant enzyme present in prokaryotic and eukaryotic cells as a first line of defense against the accumulation of superoxide radicals [54].The effects of treatment with different *Lycium barbarum* leaf extract concentrations on SOD enzyme activity in cherry tomatoes were similar at 5 °C (Figure 8B) to those at 20 °C (Figure 8A); there was an overall trend of increasing and then decreasing. The coloration (a/b) was significantly higher for tomatoes treated with *Lycium barbarum* leaf extract at concentrations of 0.2, 0.4, and 0.6 g/L compared with CK throughout the storage period ($p < 0.05$). After storage for 21 days at 20 °C, SOD activity was lower in tomatoes treated with *Lycium barbarum* leaf extract at 0.8 g/L and 1.0 g/L compared with CK, and SOD enzyme activity for the other treatments followed the order of: 0.4 g/L > 0.2 g/L > 0.6 g/L (Figure 8A). Thus, high *Lycium barbarum* leaf extract concentrations were not effective at delaying the decline in SOD enzyme activity at 20 °C, and the effectiveness at preservation was lower compared with the other concentrations.

SOD enzyme activity was higher in tomatoes treated with *Lycium barbarum* leaf extract during storage compared with CK. However, all of the different *Lycium barbarum* leaf extract concentrations effectively delayed the decline in the SOD enzyme activity in tomatoes during storage at 5 °C, thereby maintaining the balance of ROS production and removal. *Lycium barbarum* leaf extract at 1.0 g/L was the most effective treatment.

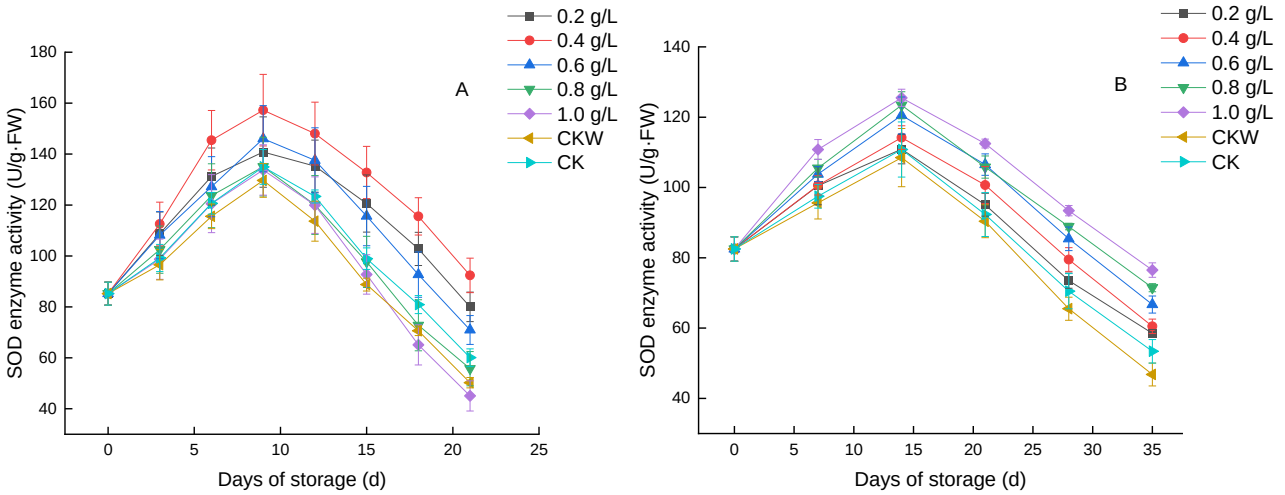


Figure 8. Effects of different *Lycium barbarum* leaf extract concentrations on SOD activities in cherry tomatoes at 20 °C (**A**) and 5 °C (**B**).

3.9. Effects of Different Lycium barbarum Leaf Extract Concentrations on TSS Content of Cherry Tomatoes

The TSS content is an important quality indicator for measuring the sweetness of cherry tomatoes [55]. At 20 °C (Figure 9A), the TSS content of tomatoes increased with storage time under all treatments. During the storage period, the TSS content was lower under treatment with *Lycium barbarum* leaf extract at 0.2, 0.4, and 0.6 g/L compared with CK, and 0.4 g/L was most effective at preservation. After storage for 21 days, the TSS content of tomatoes was higher under treatment with *Lycium barbarum* leaf extract at 0.8 and 1.0 g/L compared with CK. Thus, high concentrations of *Lycium barbarum* leaf extract were not effective at enhancing preservation. At 5 °C, the TSS content of cherry tomatoes tended to increase under all treatments as storage time increased (Figure 9B). During the storage period, the TSS content was lower under each *Lycium barbarum* leaf extract treatment compared with CK. The TSS content of tomatoes under treatment with *Lycium barbarum* leaf extract followed the order of: 1.0 g/L < 0.8 g/L < 0.6 g/L < 0.4 g/L < 0.2 g/L. Thus, at 5 °C, when the *Lycium barbarum* leaf extract concentration was higher, the TSS content of cherry tomatoes increased more slowly, and their freshness was retained better.

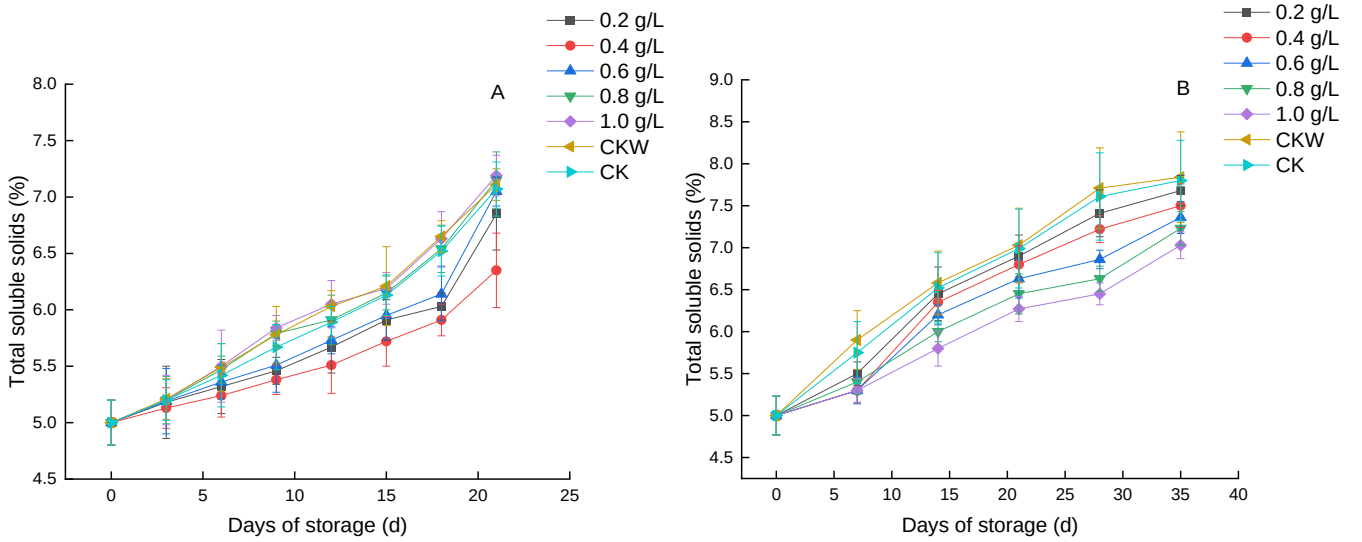


Figure 9. Effects of different *Lycium barbarum* leaf extract concentrations on the TSS content of cherry tomatoes at 20 °C (**A**) and 5 °C (**B**).

3.10. Effects of Different Lycium barbarum Leaf Extract Concentrations on TA Content of Cherry Tomatoes

During fruit ripening, organic acids serve as respiratory substrates, and they provide the intermediate metabolites required for many intracellular biochemical processes. Thus, the TA content of cherry tomatoes generally decrease during storage [56]. At 20 °C (Figure 10A), the TA content was significantly higher for tomatoes treated with *Lycium barbarum* leaf extract at 0.2, 0.4, and 0.6 g/L compared with CK throughout the storage period ($p < 0.05$), and 0.4 g/L was the most effective. At 5 °C (Figure 10B), the TA content was significantly higher under each *Lycium barbarum* leaf extract treatment compared with CK during the storage period ($p < 0.05$). The TA content under each *Lycium barbarum* leaf extract treatment followed the order of: 1.0 g/L < 0.8 g/L < 0.6 g/L < 0.4 g/L < 0.2 g/L. Thus, at 5 °C, when the concentration of *Lycium barbarum* leaf extract was lower, the reduction in TA content of cherry tomatoes was slower, and the preservation of freshness was better. The TA content gradually decreased under each treatment during storage, and the reductions were more rapid under CK compared with the *Lycium barbarum* leaf extract treatments. This was probably due to metabolic changes in the fruit caused by the consumption of organic acids in the respiratory process.

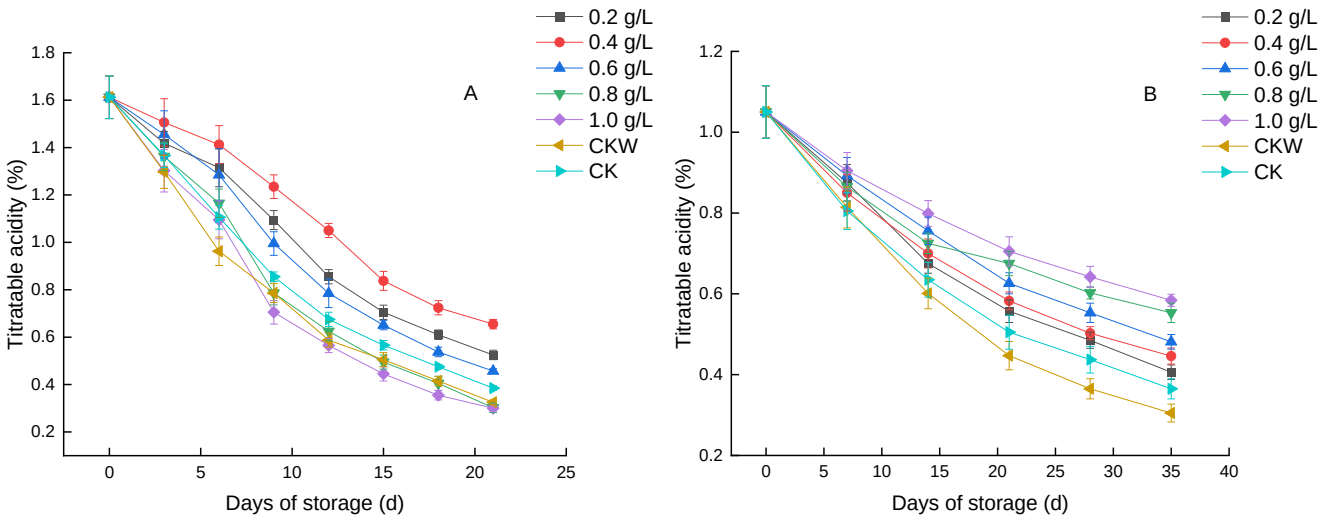


Figure 10. Effects of different *Lycium barbarum* leaf extract concentrations on the total acid content of cherry tomatoes at 20 °C (**A**) and 5 °C (**B**).

4. Discussion

In this study, the preservation effect of different concentrations of *Lycium barbarum* leaf extract was investigated when storing cherry tomatoes at low and normal temperatures, and the best freshness preservation concentration of the leaf extract of *Lycium barbarum* at different storage temperatures was screened out by determining the content of active ingredients, antioxidant capacity, and fungal inhibitory activity in the leaf extract of *Lycium barbarum* and comparing the changes of physical and chemical parameters of cherry tomatoes at different storage temperatures. This study plays an important role in comprehensively understanding and mastering the preservation of cherry tomatoes and improving their preservation effects, and it also has important guiding significance for the targeted processing and utilization of *Lycium barbarum* leaf resources.

Due to the high amount of total phenols, total flavonoids, and polysaccharides, *Lycium barbarum* leaves had high antioxidant activity and antibacterial abilities [17,20,22,23]. This study showed that the extract of *Lycium barbarum* leaves exhibited a significant preservation effect on cherry tomatoes, which not only could inhibit the growth of Penicillium that causes cherry tomato fruit decay but also could eliminate oxygen free radicals in the cherry tomato, thus slowing down the decay of the tomato fruit and maintaining its freshness.

This might be related to the phenols, polysaccharides, flavonoids and other substances contained in the leaves of *Lycium barbarum* [57,58].

According to this study, different concentrations of *Lycium barbarum* leaf extract reduced the quality loss of tomato fruits at 5 °C and 20 °C. The decrease in brightness and hardness was also mitigated, which allowed the fruits to maintain their original color and quality for a longer period of time. The chromaticity was similar to previous data on cherry tomatoes, possibly because the *Lycium barbarum* leaf extract slowed down the chlorophyll breakdown and carotenoid synthesis, thereby delaying fruit discoloration [59].Vitamin C content in cherry tomatoes increased initially but subsequently decreased with increasing storage time. Under normal storage conditions, the vitamin C content of harvested horticultural crops decreases over time, and thus the sweetness of the fruit decreases. However, we found that the vitamin C content of cherry tomatoes tended to increase initially, possibly because the cherry tomatoes used in this study were harvested in the red stage and they then entered a post-maturation stage and gradually became deep red [60]. TSS and TA content reflects the changes of sensory and nutritional quality in fruits. The flavor of cherry tomatoes is related to the balance of TSS and TA content. During the storage of cherry tomato fruits, the content of TA presented gradual declining trends. The results were comparable to the findings of Feng et al. [11]. This was probably due to the fact that organic acids are substrates for the enzymatic reactions that occur during respiration [2]. The TSS content gradually increased, which could be associated with the transformation of pectic substances and carbohydrate hydrolysis, including fruit dehydration. Therefore, suitable concentrations of *Lycium barbarum* leaf extract might maintain cherry tomato flavor for a longer period of time.

5. Conclusions

In the present study, treating cherry tomatoes with *Lycium barbarum* leaf extract considerably reduced the fruit weight loss and loss of total acid, vitamin C, and soluble solids content. It also maintained fruit color and firmness, increased SOD activity, and delayed fruit degradation and deterioration. Applying *Lycium barbarum* leaf extract at 1.0 g/L preserved the freshness of tomatoes more effectively than the other treatments at 5 °C, where the storage life was extended by 7–14 days. Applying *Lycium barbarum* leaf extract at 0.4 g/L preserved the freshness of tomatoes more effectively than the other treatments at 20 °C, where the storage life was extended by 3–6 days. Thus, *Lycium barbarum* leaf extract could be an environmentally friendly and affordable alternative to other forms of preservative techniques, whether using cold storage or normal temperature storage, for preserving harvested cherry tomatoes. The findings obtained in this study provided a theoretical basis for utilizing *Lycium barbarum* leaf extract as a natural preservative.

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