Research Article

International Journal of Agriculture and Wildlife Science

Uluslararası Tarım ve Yaban Hayatı Bilimleri Dergisi

2024, 10(1): 79 – 95, doi: 10.24180/ijaws.1428301

Preservation of Postharvest Quality of Fresh-Cut Cauliflower through Exogenous Putrescine, Citric Acid and Salicylic Acid Treatments

Taze Kesilmiş Karnabaharın Hasat Sonrası Kalitesinin Dışsal Putresin, Sitrik Asit ve Salisilik Asit Uygulamalarıyla Korunması

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Received: 30.01.2024 **Accepted:** 18.03.2024 **Published:** 29.04.2024

Abstract: Cauliflower is among the perishable vegetables after harvest. In recent years, the popularity of fresh-cut cauliflower has increased among consumers as a minimally processed product. This study was carried out to determine the effects of exogenous putrescine (PUT), citric acid (CA) and salicylic acid (SA) treatments on postharvest quality of fresh-cut cauliflower stored at 4±0.5 °C and 90±5% relative humidity for 21 days. In the study, a total of seven different treatments using two different doses (0.5 and 1.0 mM) of PUT, CA and SA were investigated. To evaluate the quality of fresh-cut cauliflower, the necessary measurements and analyzes were performed at periodic intervals on days 0, 7, 14, and 21 of storage. The results demonstrated that quality properties changed significantly depending on the postharvest treatments and storage durations. With the increase of storage duration, weight loss and ash content increased, while K, Zn and Cu contents decreased. In general, the treatments examined in the study had positive effects on postharvest quality of cauliflower. Among the treatments, especially 1.0 mM PUT was found to be more effective. Compared to the control, 1.0 mM PUT treatment decreased weight loss by 61.32%, though it increased protein content by 14.48% and P content by 21.55%. It was concluded that 1.0 mM PUT treatment can be recommended as an alternative application method to extend the storage life of fresh-cut cauliflower and reduce postharvest quality losses.

Keywords: *Brassica oleracea* L. var. *botrytis*, storage, natural compounds, quality, nutritional composition

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Öz: Karnabahar hasattan sonra çabuk bozulan sebzeler arasında yer almaktadır. Son yıllarda minimal işlenmiş bir ürün olarak taze kesilmiş karnabaharın tüketiciler arasında popülaritesi artmıştır. Bu çalışma, 21 gün boyunca 4±0.5 °C ve %90±5 nispi nemde muhafaza edilen taze kesilmiş karnabaharın hasat sonrası kalitesi üzerine dışsal putresin (PUT), sitrik asit (CA) ve salisilik asit (SA) uygulamalarının etkilerini belirlemek için yürütülmüştür. Çalışmada PUT, CA ve SA'nın iki farklı dozunun (0.5 ve 1.0 mM) kullanıldığı toplam yedi farklı uygulama araştırılmıştır. Taze kesilmiş karnabaharın kalitesini değerlendirmek için gerekli ölçüm ve analizler muhafazanın 0, 7, 14 ve 21. günlerinde periyodik aralıklarla yapılmıştır. Sonuçlar kalite özelliklerinin hasat sonrası uygulamalara ve muhafaza sürelerine bağlı olarak önemli ölçüde değiştiğini göstermiştir. Muhafaza süresinin artmasıyla birlikte ağırlık kaybı ve kül içeriği artarken, K, Zn ve Cu içerikleri azalmıştır. Genel olarak çalışmada incelenen uygulamaların karnabaharın hasat sonrası kalitesi üzerine olumlu etkileri olmuştur. Uygulamalar arasında özellikle 1.0 mM PUT'un daha etkili olduğu bulunmuştur. Kontrol ile karşılaştırıldığında 1.0 mM PUT uygulaması ağırlık kaybını %61.32 oranında azaltırken, protein içeriğini %14.48 ve P içeriğini %21.55 oranında artırmıştır. Taze kesilmiş karnabaharın muhafaza ömrünü uzatmak ve hasat sonrası kalite kayıplarını azaltmak için 1.0 mM PUT uygulamasının alternatif bir uygulama yöntemi olarak önerilebileceği sonucuna varılmıştır.

Anahtar Kelimeler: *Brassica oleracea* L. var. *botrytis*, muhafaza, doğal bileşikler, kalite, besin kompozisyonu

Cite as: Kibar, B., Kibar, H., & Gündehabar, E. (2024). Preservation of postharvest quality of fresh-cut cauliflower through exogenous putrescine, citric acid and salicylic acid treatments. International Journal of Agriculture and Wildlife Science, 10(1), 79-95. doi: 10.24180/ijaws.1428301

Plagiarism/Ethic: This article has been reviewed by at least two referees and it has been confirmed that it is plagiarism-free and complies with research and publication ethics. https://dergipark.org.tr/tr/pub/ijaws

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INTRODUCTION

Cauliflower (*Brassica oleracea* L. var. *botrytis*) is an important vegetable that belongs to the Brassicaceae (Cruciferae) family and is widely distributed in the Mediterranean countries. It is well known worldwide and has great economic benefits. The edible part of cauliflower is the immature inflorescence. The parts of cauliflower consumed as vegetable are called as curd. It is an important component of human diet. It is quite delicious and can be eaten raw, cooked or pickled. It is defined as a vegetable with high nutritional value because of important vitamins, antioxidants and anti-carcinogenic compounds it contains (Lee and Kader, 2000). Cauliflower is widely consumed due to its unique taste, nutritional value, and bioactive compounds such as glucosinolates (*GLSs*), carotenoids, phenolic compounds and ascorbic acid (Avato and Argentieri, 2015). It is a good source of vitamins (B1, B2, B3, B5, B6, C, E and K), protein, minerals (phosphorus, potassium, iron, magnesium and manganese), dietary fiber, folic acid and omega-3 fatty acids (Florkiewicz et al., 2014). It has many health benefits such as providing protection against various diseases. Cauliflower is rich in glucosinolates (anticancer compounds), a class of secondary metabolites in plants that have anticarcinogenic properties (Holst and Williamson, 2004). It is reported that the consumption of vegetables rich in glucosinolates, including cauliflower, can significantly reduce the risk of cancer (Lampe and Peterson, 2002; Neuhouser et al., 2003).

Cauliflower is a popular and important vegetable that is widely grown in Turkey. In Turkey, cauliflower was grown in an area of 86.771 da with a production of 239.857 tons in 2022 (TÜİK, 2023). In recent years, cauliflower cultivation in our country has been increasing rapidly due to the increase in demand, its sale in the market at higher prices than other cabbage group vegetables, and its higher income per unit area.

However, it is among the perishable vegetables after harvest. As cauliflower heads (curds) have a high respiration rate and water loss, their storage life is short (Kader, 2002). Cauliflower, with its high moisture content, is susceptible to microbial spoilage. It inflorescences are harvested while they are totally immature. Major postharvest problems affecting the shelf life of fresh cauliflower heads during marketing are yellowing and browning of heads, bitterness, softening, microbial attacks and spoilage, undesirable odor development and discoloration (Hodges et al., 2006; Licciardello et al., 2013; Zhan et al., 2014). These negativities affect consumer behavior and directly decrease consumer purchase.

Nowadays, with changes in lifestyle and consumption habits, there has been increasing interest in fresh-cut cauliflower as a minimally processed product (Sanz-Cervera et al., 2007). As consumer preferences for ready-to-use or ready-to-eat vegetables increase, fresh-cut or minimally processed cauliflower is becoming much more common as a convenience product in food services and retail markets (Escalona et al., 2007). The quality of fresh-cut cauliflower, usually sold in supermarkets, can easily deteriorate. The perishable nature of fresh-cut cauliflower is a limiting factor that reduces its consumption due to its short shelf life after harvest (Hodges et al., 2006). Consumers demand fresh and high-quality product with minimal changes in their nutritional and sensory properties during processing and storage. The quality of fresh-cut cauliflower is a combination of characteristics such as appearance, texture, color, flavor and nutritional value. Studies carried out to extend the shelf life and to reduce the nutritional loss of fresh-cut cauliflower during postharvest are of great importance.

In recent years, in addition to different preservation techniques, natural compounds such as polyamines (putrescine, spermine and spermidine), citric acid and salicylic acid have been used to decrease postharvest quality losses and extend the storage life of fresh-cut vegetables. Studies investigating the effects of the postharvest use of these compounds on the storage time and quality of different vegetables have increased. By treating fresh-cut vegetables with low-dose solutions of these compounds after harvest, quality can be preserved and storage time can be increased. On the other hand, the effectiveness of these compounds vary depending on many factors such as species, variety, application method, application time, application dose and environmental conditions (Horvath et al., 2007).

Polyamines (PAs), which are one of the substances used to protect or improve the postharvest quality of products, are low molecular weight organic compounds that occur naturally in plants (Khosroshahi et al., 2007). The most common PAs found in plants are reported to be putrescine, spermidine and spermine

(Takahashi and Kakehi, 2010). Among the PAs, putrescine (PUT) is generally found in the highest amount (Kalac and Krausova, 2005). In studies conducted on different vegetables, it has been reported that postharvest PA application delays ripening and aging, slows down the softening of fruit flesh, inhibits ethylene production and activity, controls respiration rate, and affects the postharvest shelf life and quality of the product (Gonzalez-Aguilar et al., 2000; Palma et al., 2014; Jia et al., 2018). Salicylic acid (SA) is an endogenous plant growth regulator that functions in the regulation of physiological events in plants (Hayat et al., 2010). It is a natural and safe phenolic compound produced by plants (Rivas-San Vicente and Plasencia, 2011). SA inhibits ethylene biosynthesis and delays aging (Özeker, 2005). SA has high potential to extend the postharvest storage life of fruits and vegetables and maintain their sensory and nutritional quality (Asghari and Aghdam, 2010). It has been reported that exogenous application of SA in horticultural crops is effective in maintaining postharvest quality (Asghari and Aghdam, 2010; Davarynejad et al., 2015; Dokhanieh and Aghdam, 2016). Citric acid (CA) is an organic acid and increases the postharvest storage life of horticultural products and affects the quality. It is widely used in the food industry as a preservative. It is one of the substances used to prevent darkening (Garcia and Barrett, 2002). It has been determined that the polyphenol oxidase (PPO) enzyme, which is associated with enzymatic darkening, is blocked by CA (Pizzocaro et al., 1993). Recently, researchers have focused on exogenous CA applications to maintain postharvest quality in horticultural crops (Manolopoulou and Varzakas, 2014; Kasım and Kasım, 2016; Ozturk et al., 2021).

Previous studies have shown that exogenously applied PUT, CA and SA reduce the losses in postharvest quality parameters in vegetables (Jia et al., 2018; Davras et al., 2019; Motamedi et al., 2020; Üner, 2021; Şahin, 2022; Kibar et al., 2023). However, there is little information on the effect of these compounds on the postharvest quality and shelf life of fresh-cut cauliflower. Therefore, the purpose of this study was to determine the influence of exogenous PUT, CA and SA treatments on postharvest quality (i.e., weight loss, total soluble solids, pH, ash, dry matter, color, protein and mineral contents) of fresh-cut cauliflower stored at 4 ± 0.5 ˚C and 90 ± 5% relative humidity for 21 days.

MATERIAL AND METHOD

Material

Fremont F1 cauliflower variety (*Brassica oleracea* L. var. *botrytis*) was used in the study. Sixty firm, compact, healthy, and medium size cauliflower heads were harvested at the commercial maturity stage from the field of a commercial farmer in Bolu, Türkiye. To ensure homogeneity in the experiment, cauliflower heads at the same size and maturity stage were selected. There was no disease, insect damage or mechanical damage in the cauliflower heads. After harvesting, the leaves were removed and the stalks were cut. Cauliflower heads were immediately transported to the laboratory in plastic crates.

PUT and SA used in the study were purchased from Sigma-Aldrich company, and CA was purchased from Akbel Kimya company.

Experimental Design, Treatments and Sample Preparation

The experiment was established in a completely randomized design (CRD) with three replications and each replication contained three packages containing 800 g of fresh-cut cauliflower sample. In the study, a total of seven different treatments using two different doses (0.5 and 1.0 mM) of PUT, CA and SA were investigated (Table 1). No PUT, CA and SA was added to the control application.

After the outer leaves were removed, cauliflower inflorescences were cut with a stainless steel knife into single florets of 30-60 g each by carefully separating the florets from the main stem. The total soluble solids, pH, ash, dry matter, color, protein and mineral contents of the initial fresh-cut cauliflower sample were determined. Fresh-cut cauliflower samples were divided into seven equal groups for treatments. Then, the samples were subjected to the treatments in the study. PUT, CA and SA solutions were prepared at the doses discussed in the study, and postharvest treatments were made by dipping cauliflower samples into the solutions. The samples were immersed in 2 L of solutions (Table 1) at 4 °C containing 0.01% dose of Tween 20 used as an adhesive and left for 5 min. Control group samples were similarly immersed in distilled water at 4 °C containing 0.01% dose of Tween 20 used as an adhesive and kept for 5 min. After the

dipping process, all samples were kept on drying papers for 30 min at room conditions (20-23 °C and 50-60% relative humidity) to remove excess water. Five holes with a diameter of 2 mm were drilled on the lids of the transparent plastic containers to be used for preservation. Then, 800 g of the cauliflower sample was weighed, placed in 2 L transparent plastic containers with lids and closed.

Table 1. Treatments used in the study.
Çizelge 1. Çalışmada kullanılan uygulamalar.

Treatment	Abbreviation
Control	Control
0.5 mM Putrescine	0.5 mM PUT
1.0 mM Putrescine	1.0 mM PUT
0.5 mM Citric Acid	0.5 mM CA
1.0 mM Citric Acid	1.0 mM CA
0.5 mM Salicylic Acid	0.5 mM SA
1.0 mM Salicylic Acid	1.0 mM SA

Storage

The samples, packaged in triplicate, were immediately placed on shelves in the cold storage room and stored for 21 days at 4±0.5 °C and 90±5% relative humidity. To evaluate the quality of fresh-cut cauliflower, measurements and analyzes were performed at periodic intervals on days 0, 7, 14, and 21 of storage.

Determination of Weight Loss (WL)

Initial fresh weight of each packet was determined immediately after treatments before storage. WL was detected by regularly weighing the cauliflower samples at different storage days (7, 14, and 21) and expressed as percentage WL. The samples were weighed on a precision balance with a precision of 0.01 g. On days 7, 14 and 21, the differences compared with the initial weight. WL was calculated using the following formula as stated in the study of Hodges et al. (2006).

$$WL\ (\%) = \frac{(FW_0 - FW_r)}{FW_0} \times 100 \quad (1)$$

where;

FW_0 = fresh weight of cauliflower before storage, g

FW_r = fresh weight of cauliflower at 7, 14 and 21 d of storage, g

Determination of Dry Matter, Ash, Total Soluble Solids (TSS) and pH Contents

The dry matter content of the cauliflower samples was determined by using the procedures of AOAC (1990) and expressed as percentage.

The ash content was detected by burning the dried samples in a ash oven (Mipro MKF, Ankara, Türkiye) at 550 °C for about 8 h until gray white ash was obtained (AOAC, 1990). The ash content was expressed as percentage.

To determine TSS, cauliflower sample consisting of florets and stems was juiced using a commercial home juicer. TSS was measured with a hand-held refractometer (ATC-1, Atago, Japan) and expressed as percentage.

For pH measurement, 25 g of cauliflower sample was kept in a beaker with 100 mL of pure water at room temperature (23±1.5 °C) for 24 h. Then, the pH values of the samples were measured using a digital pH meter (Thermo Scientific, Orion Star A111, USA).

Determination of Protein Content

The total nitrogen (N) content of cauliflower samples was determined according to Kjeldahl method. The protein content (Nx6.25) was calculated as described by AOAC (1990) and expressed as percentage.

Determination of Mineral Element Contents

To determine element contents [phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu)], all samples were dried in an oven at 65 °C until they reached a constant weight. Then, dried cauliflower samples were ground into powder by using a grinder (MC23200, Siemens, Germany). Subsequently, the samples prepared for analysis according to the microwave digestion method. Element contents were detected using inductively coupled plasma mass spectrometry (ICP-MS; Thermo Scientific, X Series, Cambridge, U.K.). Phosphorus content was determined by UV-visible spectrophotometer (UV-1800, Shimadzu, Japan). Mineral element contents were expressed as mg kg^{-1} dry weight (DW).

Determination of Color

The color of cauliflower samples was measured by using a digital colorimeter (3NH NR60CP, Shenzhen, China) at different storage days (0, 7, 14 and 21) and expressed as L*, a*, b*, Chroma and Hue angle values. Color was measured at five different points on the surface of the cauliflower florets from each replicate per treatment.

Statistical Analysis

The experiment was conducted in a completely randomized design (CRD) with three replications. All chemical analyzes were performed in triplicate. The results obtained were expressed as mean ± standard deviation. Data were analyzed to two-factor analysis of variance to define the effects of the main factors and interactions (SD × T); wherein storage duration (SD) and traetments (T) were regarded as the main factors (JMP software version 13.2; SAS Institute Inc., Cary, North Carolina, USA). The differences among means were determined by the Tukey's HSD test ($P < 0.05$).

RESULTS AND DISCUSSION

Changes in WL, Dry Matter, Ash, TSS and pH Contents

The analysis of variance showed that the difference among the storage durations in terms of WL, ash, TSS and pH content was statistically significant ($P<0.01$). On the other hand, no statistically significant difference was found among the storage durations in terms of dry matter content. There were significant differences in terms of all the examined properties except pH among the treatments. When the interaction between storage durations and treatments was examined, it was found to be significant ($P<0.01$) in terms of all the examined properties (Table 2).

When the effect of storage durations on WL was examined, the highest WL was found on the 21st day (1.89%). It was determined that WL increased regularly during storage. Among the treatments, the highest values in terms of WL were detected in 0.5 mM SA and control (1.73 and 1.71%, respectively), whereas the lowest WL was observed in 1.0 mM PUT treatment with 1.06%. It was determined that 1.0 mM PUT treatment reduced WL by 61.32% compared with the control. Post-harvest treatments in the study had a positive effect on WL of cauliflower. Compared to the control, the lower values in terms of WL were obtained from all treatments except 0.5 mM SA. In the present study, WL differed significantly according to different storage durations and treatments. WL varied between 0.70% (Day 7×1.0 mM PUT) and 2.40% (Day 21×Control). The highest dry matter content was found in 0.5 mM PUT treatment, while the lowest values for dry matter content were observed in control, 0.5 CA, 1.0 CA and 1.0 SA treatments. Depending on different storage durations and treatments investigated in the study, dry matter content varied from 7.35% (Day 7×1.0 mM SA) to 8.94% (Day 21×0.5 mM PUT). When storage durations were examined, the highest ash content was detected on the 21st day. With the increase in storage duration, the ash content also increased. Compared with before storage, ash content increased significantly after storage. Among the treatments, maximum ash contents were found in 1.0 mM PUT and 0.5 mM SA, whereas minimum ash contents were observed in 0.5 mM PUT and 0.5 mM CA. The ash content varied from 5.10 to 9.86% depending on storage duration × treatment interaction. Compared to before storage, TSS content decreased significantly after storage. TSS contents fluctuated depending on storage duration. TSS content increased on the 14th day of storage and decreased on the 21st day. Among the treatments, maximum TSS content was found in 0.5 mM PUT (6.43%), whereas minimum TSS content was recorded in 0.5 mM SA and 1.0 mM SA treatments with 5.28%. When storage duration × treatment interaction was examined, TSS content

ranged from 4.75 to 7.30%. In the current study, pH contents fluctuated depending on storage duration. The highest pH value was determined on the 7th day, while the lowest pH value was detected on the 14th day. In general, pH content decreased on the 14th day of storage and increased on the 21st day. Depending on different storage durations and treatments discussed in the study, pH value varied from 6.07 to 7.15.

Loss in weight during storage of vegetables is considered as a quality decrease parameter. The high respiration rate of vegetables causes an increase in WL during storage and a short shelf life. WL is mainly due to water loss in vegetables through transpiration and evaporation of water. Vegetables are particularly vulnerable to quick water loss (Kays, 1991). Water loss is an important factor in shortening the storage life of fresh products by affecting their deterioration during storage (Pan and Sasanatayart, 2016). Similar to our findings, previous studies found that WL of fresh-cut cauliflower increased continuously during cold storage (Miceli et al., 2015; Kasim and Kasim, 2017; Giuffrida et al., 2018; Madonna et al., 2018; Nasrin et al., 2022). Dhall et al. (2010) determined that WL varied between 1.70-4.25% after 21-day storage at 0±1 °C in cauliflower, which was consistent with our findings. Kibar et al. (2023) reported that SA, CA and PUT applications decreased significantly weight loss of broccoli stored at 4 °C for 21 days compared to the control, which was compatible with our results. In another study, the effect of PUT, SA and CA treatments on WL of *Pleurotus ostreatus* mushroom stored at 4 °C for 14 days was found to be insignificant (Şahin, 2022). In the study conducted on cucumber by Jia et al. (2018), it was found that WL could be reduced with PUT application. Our results are consistent with the researchers' findings. It was stated that CA treatments significantly reduced WL of *Agaricus bisporus* mushroom at the end of the storage period compared to the control (Lagnika et al., 2014; Khan et al., 2015; Gupta and Bhat, 2016). Alali et al. (2023) reported that CA has the ability to close stomata, reduce transpiration rates, and decrease WL in fruits and vegetables. In studies conducted on cucumber (Altıkardeş et al., 2018), tomato (Davras et al., 2019) and parsley (Üner, 2021), it was determined that postharvest SA applications significantly reduced WL at the end of the storage period compared to the control.

The dry matter amount of fresh-cut cauliflower decreased during cold storage (14 days at 4 °C) and also decreased at the end of the storage period compared to before storage (Giuffrida et al., 2018). Since dry matter is used in respiration, a decrease in the amount of dry matter during storage is an expected result. On the contrary, Cebula et al. (2006) reported that the dry matter content of cauliflower stored at 2 °C for 5 weeks increased after storage compared to before storage. In another study, the effect of PUT, SA and CA applications on dry matter amount of *Pleurotus ostreatus* mushroom stored at 4 °C for 14 days was found to be insignificant. It was also reported that dry matter amount decreased as storage time increased (Şahin, 2022). Ozturk et al. (2021) stated that CA application generally caused a decrease in dry matter amount of *Cantharellus cibarius* mushroom stored at 0 °C for 12 days compared to the control.

The ash content of vegetables typically consists of various minerals such as potassium, calcium, phosphorus and magnesium. The change in the ash content of vegetables during the storage period directly affects the change in mineral content. Similar to our findings, it was stated that the ash content of broccoli stored at 4 °C for 21 days increased significantly compared to before storage. Researchers also reported that there was no significant difference in terms of ash content among SA, CA, PUT and control (Kibar et al., 2023). In another study, the effect of PUT, SA and CA applications on ash content value of *Pleurotus ostreatus* mushroom stored at 4 °C for 14 days was found to be insignificant (Şahin, 2022). Ozturk et al. (2021) stated that significant increases in the amount of ash were observed in *Cantharellus cibarius* mushroom stored at 0 °C for 12 days as a natural result of water loss as the storage period progressed. Researchers also reported that the ash content in CA application was lower than the control at the end of the storage period.

Sugars constitute the majority of total soluble solid amount. The sugar content of vegetables generally decreases during post-harvest period because they are consumed through respiration and the sugar supply from the plant is interrupted (Lemoine et al., 2009). As a matter of fact, in our study, total soluble solid content of fresh-cut cauliflower decreased significantly compared to before storage. Similar to our findings, Kasim and Kasim (2017) reported that total soluble solid content of fresh-cut cauliflower stored for 28 days at 4 °C reduced significantly compared to before storage. Likewise, Giuffrida et al. (2018) determined that

total soluble solid content of fresh-cut cauliflower decreased during cold storage (14 days at 4 °C) and also decreased at the end of the storage period compared to before storage. On the other hand, Nasrin et al. (2022) found that total soluble solid content of fresh-cut cauliflower increased during 20 days of storage at 4 °C. Kibar et al. (2023) reported that TSS content of fresh-cut broccoli increased as storage time increased, and TSS content in SA, CA and PUT applications was lower than control. In terms of the soluble solid content in *Pleurotus ostreatus* mushroom stored at 4 °C for 14 days, higher values were obtained from PUT, SA and CA applications compared to the control (Şahin, 2022). It was determined that PUT and CA

Table 2. Effect of putrescine, citric acid and salicylic acid on WL, dry matter, ash, TSS and pH contents of fresh-cut cauliflower during storage at 4 °C.

Çizelge 2. 4 °C'de muhafaza süresince taze kesilmiş karnabaharın WL, kuru madde, kül, TSS ve pH içerikleri üzerine putresin, sitrik asit ve salisilik asidin etkisi.

Storage duration (SD)	WL (%)	Dry matter (%)	Ash (%)	TSS (%)	pH
Before storage	0.00±0.00 D	8.23±0.33 ns	7.56±0.60 C	8.00±0.45 A	6.49±0.13 B
Day 7	0.86±0.15 C	8.03±0.52 ns	7.67±1.23 BC	5.53±0.78 C	7.10±0.10 A
Day14	1.58±0.30 B	7.95±0.44 ns	8.42±0.56 AB	6.40±0.55 B	6.15±0.15 C
Day 21	1.89±0.34 A	8.20±0.61 ns	9.06±0.72 A	5.54±0.72 C	6.60±0.20 B
Treatment (T)					
Before storage	0.00±0.00 B	8.23±0.23 AB	7.56±0.12 B	8.00±0.45 A	6.49±0.38 ns
Control	1.71±0.70 A	7.87±0.21 B	8.10±0.13 AB	5.92±0.75 BC	6.53±0.44 ns
0.5 mM PUT	1.28±0.36 A	8.66±0.56 A	7.58±0.45 B	6.43±0.68 B	6.64±0.46 ns
1.0 mM PUT	1.06±0.30 A	8.20±0.26 AB	9.24±0.51 A	6.22±0.40 BC	6.68±0.37 ns
0.5 mM CA	1.35±0.44 A	7.96±0.38 B	7.44±1.81 B	5.97±0.82 BC	6.66±0.49 ns
1.0 mM CA	1.37±0.49 A	7.91±0.55 B	8.50±0.78 AB	5.67±1.05 BC	6.48±0.46 ns
0.5 mM SA	1.73±0.52 A	7.99±0.72 AB	9.26±0.39 A	5.28±0.57 C	6.68±0.40 ns
1.0 mM SA	1.59±0.45 A	7.84±0.48 B	8.57±0.59 AB	5.28±0.50 C	6.63±0.43 ns
SD × T					
Before storage	0.00±0.00 l	8.23±0.23 ab	7.56±0.12 fgh	8.00±0.25 a	6.49±0.12 efg
Day 7×Control	0.83±0.07 ijk	8.05±0.10 ab	8.05±0.12 efg	6.45±0.45 bcd	7.07±0.12 a-d
Day 14×Control	1.90±0.10 bcd	7.90±0.20 ab	8.10±0.20 efg	6.30±0.30 cd	6.09±0.09 h
Day 21×Control	2.40±0.20 a	7.67±0.10 ab	8.16±0.10 cde	5.00±0.25 gh	6.43±0.10 e-h
Day 7×0.5 mM PUT	0.82±0.08 ijk	8.57±0.20 ab	7.17±0.17 h	6.00±0.22 def	7.12±0.12 ab
Day 14×0.5 mM PUT	1.42±0.08 gh	8.48±0.20 ab	7.56±0.10 fgh	7.30±0.13 ab	6.09±0.10 h
Day 21×0.5 mM PUT	1.59±0.10 efg	8.94±1.00 a	8.00±0.52 efg	6.00±0.32 def	6.72±0.08 cde
Day 7×1.0 mM PUT	0.70±0.15 k	8.39±0.40 ab	8.75±0.25 bc	6.45±0.45 bcd	7.07±0.07 a-d
Day 14×1.0 mM PUT	1.12±0.08 hi	8.14±0.14 ab	9.10±0.13 b	6.20±0.20 cde	6.25±0.15 fgh
Day 21×1.0 mM PUT	1.36±0.04 gh	8.06±0.06 ab	9.86±0.10 a	6.00±0.51 def	6.73±0.07 b-e
Day 7×0.5 mM CA	0.79±0.10 jk	7.68±0.20 ab	5.10±0.21 i	5.00±0.52 gh	7.15±0.15 a
Day 14×0.5 mM CA	1.48±0.10 fg	7.82±0.10 ab	8.14±0.14 def	6.20±0.30 cde	6.07±0.07 h
Day 21×0.5 mM CA	1.77±0.10 c-f	8.37±0.37 ab	9.09±0.09 b	6.70±0.35 bcd	6.77±0.13 a-e
Day 7×1.0 mM CA	0.77±0.04 jk	7.66±0.20 ab	7.53±0.23 gh	5.00±0.50 gh	7.08±0.12 a-d
Day 14×1.0 mM CA	1.45±0.15 g	7.99±1.00 ab	8.71±0.20 bcd	7.00±0.25 bc	6.10±0.13 gh
Day 21×1.0 mM CA	1.89±0.10 b-e	8.08±0.20 ab	9.27±0.12 ab	5.00±0.25 gh	6.27±0.10 fgh
Day 7×0.5 mM SA	1.05±0.10 ij	8.52±0.50 ab	8.93±0.07 b	5.05±0.20 fgh	7.10±0.12 abc
Day 14×0.5 mM SA	2.01±0.10 bc	7.49±0.10 b	9.10±0.12 b	6.00±0.15 def	6.26±0.26 fgh
Day 21×0.5 mM SA	2.13±0.07 ab	7.96±1.00 ab	9.76±0.10 a	4.80±0.20 h	6.69±0.22 de
Day 7×1.0 mM SA	1.04±0.06 ij	7.35±0.35 b	8.16±0.16 cde	4.75±0.25 h	7.11±0.11 abc
Day 14×1.0 mM SA	1.65±0.10 d-g	7.85±0.10 ab	8.25±0.25 cde	5.80±0.22 d-g	6.17±0.17 gh
Day 21×1.0 mM SA	2.07±0.03 bc	8.31±0.31 ab	9.30±0.30 ab	5.30±0.33 e-h	6.60±0.15 ef
Significant effects (P values)					
SD	0.0001	0.4463	0.0001	0.0001	0.0001
T	0.0001	0.0106	0.0001	0.0001	0.9531
SD × T	0.0001	0.0071	0.0001	0.0001	0.0001

PUT: Putrescine; CA: Citric acid; SA: Salicylic acid; WL: Weight loss; TSS: Total soluble solids; ±: Standard deviation of mean; ns: non-significant.

applications increased the amount of total soluble solid compared to the control in *Agaricus bisporus* mushroom (Motamedi et al., 2020). Similarly, in the study conducted on cucumber by Jia et al. (2018), it was found that soluble solid content decreased during the storage period, and the amount of total soluble solid in PUT application was significantly higher than the control at the end of the storage period. Accordingly, the results obtained in the current study are consistent with findings of Jia et al. (2018). It was reported that the amount of total soluble solid in fresh-cut broad bean decreased during the storage period, and that the amount of total soluble solid in CA applications was higher than in the control at the end of the storage period (Kasım and Kasım, 2016). In studies conducted on tomato (Akbulut, 2015) and pepper (Gülsoylu, 2015), soluble solid content in SA treatments was found to be higher than in the control at the end of the storage period. Davras et al. (2019) and Üner (2021) reported that no significant difference was observed between control and SA applications in terms of soluble solid content in tomato and parsley during storage.

The change in pH during storage is associated with the growth of microorganisms and the resulting production of organic acids (Heard, 2002). Miceli et al. (2015) reported that pH value of minimally processed cauliflower decreased during storage (21 days at 4 °C). On the other hand, Nasrin et al. (2022) found that pH increased in fresh-cut cauliflower during 20 days of storage at 4 °C. Kibar et al. (2023) reported that effect of SA, CA and PUT applications on pH value of fresh-cut broccoli was found to be insignificant. Likewise, the effect of PUT, SA and CA on pH value of *Pleurotus ostreatus* mushroom stored at 4 °C for 14 days was found to be insignificant. It was also reported that pH value increased as storage time increased (Şahin, 2022). Our findings are similar to the results of Şahin (2022) and Kibar et al. (2023). Kasım and Kasım (2016) investigated the effects of CA applications at different doses on postharvest quality of fresh-cut broad bean. At the end of the storage period, the pH value in CA applications was found to be lower than the control. In studies conducted on pepper (Gülsoylu, 2015) and tomato (Davras et al., 2019), it was found that the pH value increased during storage and that the pH value in SA applications was lower than the control at the end of the storage period. It was determined that the effect of SA on pH in grated carrot stored at 4 °C for 10 days was insignificant (Ergun and Kösetürkmen, 2008).

Changes in Protein and Mineral Contents

As seen in Table 3, there were statistically significant differences among storage durations for K, Zn and Cu contents, while no statistically significant difference was found among storage durations for protein, P, Mg, Ca, Fe and Mn contents. The effects of treatments on protein, P, K, Mg, Ca, Fe, Mn, Zn and Cu contents of cauliflower were statistically significant. Similarly, storage duration × treatment interaction in terms of the nutritional properties mentioned above were found to be statistically significant.

When the effect of treatments on protein content was examined, 1.0 mM PUT possessed the highest value with 17.63%, though the lowest values were recorded in control and 1.0 mM CA treatments. In the current study, it was determined that all treatments significantly increased protein content compared to the control. It was found that 1.0 mM PUT treatment increased protein content by 14.48% compared with the control. The protein content varied from 14.81 (Day 21×Control) to 18.13% (Day 21×1.0 mM SA) depending on storage duration × treatment interaction. Among the treatments, the highest P content was determined in 1.0 mM PUT and 0.5 mM SA, though the lowest P content was detected in control and 0.5 mM PUT. The higher values in terms of P content were obtained from all treatments except 0.5 mM PUT compared to the control. It was determined that 1.0 mM PUT treatment increased P content by 21.55% compared with the control. Regarding storage duration × treatment interaction, it was found that the highest P content (5616 mg kg^{-1}) was detected in Day 7×1.0 mM PUT treatment, while the lowest P content (3989 mg kg^{-1}) was observed in Day 14×Control treatment. Compared with before storage, K content decreased significantly after storage. With the increase in storage duration, the K content decreased. When the effect of treatments on K content was examined, the highest values were found in 1.0 mM PUT and 1.0 mM SA treatments. On the other hand, the lowest K content was observed in 0.5 mM PUT. Depending on different storage durations and treatments investigated in the study, K content varied from 21780 (Day 21×Control) to 27740 (Day 7×1.0 mM SA) mg kg^{-1}. Among the treatments, the highest Mg and Ca contents were obtained from 1.0 mM SA, while the lowest values for Mg and Ca were recorded in 0.5 mM PUT. Compared with the

control, 1.0 mM SA treatment increased Mg and Ca contents by 13.38% and 22.46%, respectively. Mg and Ca contents varied from 1419 to 1949 mg kg^{-1} and 4425 to 6977 mg kg^{-1}, respectively, depending on storage duration × treatment interaction.

Table 3. Effect of putrescine, citric acid and salicylic acid on protein, P, K, Mg, Ca, Fe, Mn, Zn and Cu contents of fresh-cut cauliflower during storage at 4 °C.

Çizelge 3. 4 °C'de muhafaza süresince taze kesilmiş karnabaharın protein, P, K, Mg, Ca, Fe, Mn, Zn ve Cu içerikleri üzerine putresin, sitrik asit ve salisilik asidin etkisi.

Storage duration (SD)	Protein (%)	P (mg kg^{-1})	K (mg kg^{-1})	Mg (mg kg^{-1})	Ca (mg kg^{-1})
Before storage	17.64±1.03 ns	4683±410 ns	26020±1036 A	1695±110 ns	4875±442 ns
Day 7	16.50±1.40 ns	4728±609 ns	24749±2345 A	1689±206 ns	5398±763 ns
Day14	16.51±1.41 ns	4677±431 ns	23868±1275 AB	1699±162 ns	5340±522 ns
Day 21	16.31±1.78 ns	4611±340 ns	23029±1334 B	1651±144 ns	5273±601 ns
Treatment (T)					
Before storage	17.64±1.07 A	4683±241 ABC	26020±1012 A	1695±106 ABC	4875±203 DE
Control	15.40±1.59 B	4190±263 C	23470±2187 AB	1622±104 BC	4969±246 CDE
0.5 mM PUT	15.89±0.75 AB	4181±330 C	22309±1295 B	1482±159 C	4622±309 E
1.0 mM PUT	17.63±1.08 A	5093±443 A	24813±655 A	1749±149 AB	6019±379 AB
0.5 mM CA	16.61±1.06 AB	4939±279 AB	24092±1202 AB	1616±167 BC	5220±209 CD
1.0 mM CA	15.54±1.35 B	4761±234 AB	24667±1535 AB	1722±116 AB	5506±237 BC
0.5 mM SA	16.84±0.69 AB	5035±316 A	22747±1056 AB	1728±121 AB	4939±201 DE
1.0 mM SA	17.18±2.28 AB	4505±304 BC	25075±2570 A	1839±145 A	6085±716 A
SD × T					
Before storage	17.64±1.22 ab	4683±110 b-e	26020±1012 ab	1695±98 abc	4875±217 e-i
Day 7×Control	15.31±1.21 bc	4215±190 cde	25810±1986 abc	1612±19 abc	4812±190 f-i
Day 14×Control	16.07±2.25 b	3989±185 e	22820±978 bc	1731±31 abc	4971±297 d-i
Day 21×Control	14.81±2.18 c	4365±286 b-e	21780±995 c	1524±102 abc	5124±208 d-i
Day 7×0.5 mM PUT	15.31±0.32 bc	4000±470 de	21920±1055 bc	1419±210 c	4763±195 ghi
Day 14×0.5 mM PUT	15.94±1.08 bc	4215±106 cde	22856±1995 bc	1480±202 bc	4678±305 hi
Day 21×0.5 mM PUT	16.44±0.44 b	4329±205 b-e	22150±1024 bc	1546±96 abc	4425±382 i
Day 7×1.0 mM PUT	17.96±2.00 a	5616±224 a	24950±950 abc	1661±103 abc	5706±303 b-e
Day 14×1.0 mM PUT	17.50±0.52 ab	4826±232 a-e	24840±842 abc	1729±179 abc	6105±320 bc
Day 21×1.0 mM PUT	17.44±0.44 ab	4838±307 a-e	24650±205 abc	1856±101 ab	6245±375 ab
Day 7×0.5 mM CA	17.64±1.00 ab	5005±395 abc	24420±2160 abc	1642±202 abc	5212±202 d-i
Day 14×0.5 mM CA	16.25±0.25 b	4975±306 abc	24315±353 abc	1685±198 abc	5269±210 d-h
Day 21×0.5 mM CA	15.94±1.03 bc	4836±212 a-e	23541±1096 bc	1520±105 bc	5178±296 d-i
Day 7×1.0 mM CA	16.50±0.50 b	4867±214 a-d	25820±1998 abc	1750±187 abc	5356±287 c-h
Day 14×1.0 mM CA	15.12±1.02 bc	4796±208 a-e	24730±1100 abc	1730±32 abc	5615±206 b-f
Day 21×1.0 mM CA	15.00±2.04 bc	4619±306 b-e	23450±455 bc	1685±120 abc	5547±182 b-g
Day 7×0.5 mM SA	17.33±0.33 ab	5002±463 abc	22580±1036 bc	1787±186 abc	4959±123 d-i
Day 14×0.5 mM SA	16.75±1.12 b	5136±216 ab	23514±1020 bc	1712±20 abc	5012±304 d-i
Day 21×0.5 mM SA	16.44±0.44 b	4968±322 abc	22147±1021 bc	1684±108 abc	4845±222 f-i
Day 7×1.0 mM SA	15.44±1.08 bc	4390±298 b-e	27740±2080 a	1949±98 a	6977±389 a
Day 14×1.01 mM SA	17.96±2.06 a	4800±196 a-e	24000±1503 abc	1824±202 abc	5729±209 bcd
Day 21×1.0 mM SA	18.13±3.12 a	4325±205 b-e	23485±2042 bc	1745±45 abc	5548±206 b-g
Significant effects (P values)					
SD	0.5769	0.8822	0.0034	0.8216	0.5821
T	0.0042	0.0001	0.0009	0.0001	0.0001
SD × T	0.0294	0.0001	0.0001	0.0044	0.0001

PUT: Putrescine; CA: Citric acid; SA: Salicylic acid; P: Phosphorus, K: Potassium, Mg: Magnesium; Ca: Calcium; ±: Standard deviation of mean; ns: non-significant.

Table 3. Continue.
Çizelge 3. Devamı.

Storage duration (SD)	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})
Before storage	105.50±35.06 ns	22.02±3.01 ns	64.07±13.11 C	4.02±1.61 A
Day 7	166.19±79.87 ns	23.93±2.74 ns	107.3±29.64 A	2.40±1.08 AB
Day14	193.81±72.24 ns	23.01±2.15 ns	90.08±32.15 B	2.54±1.41 AB
Day 21	147.34±42.33 ns	22.91±2.14 ns	87.08±25.65 B	1.94±0.73 B
Treatment (T)				
Before storage	105.50±15.20 CD	22.00±3.10 ABC	64.00±6.03 D	4.00±0.21 A
Control	175.70±44.31 BC	21.47±1.61 BC	76.43±19.87 D	3.37±0.79 A
0.5 mM PUT	91.87±10.58 D	20.63±0.57 C	103.63±10.62 BC	2.97±0.20 AB
1.0 mM PUT	202.09±15.97 B	24.60±1.89 A	112.14±16.17 B	3.40±0.21 A
0.5 mM CA	280.07±44.18 A	24.27±1.98 AB	145.77±15.59 A	1.10±0.26 C
1.0 mM CA	164.60±12.47 BC	23.67±1.83 AB	77.07±7.72 D	1.70±0.10 C
0.5 mM SA	140.43±16.38 CD	23.50±0.62 ABC	64.40±4.81 D	1.50±0.15 C
1.0 mM SA	129.03±37.06 CD	24.87±3.42 A	84.30±18.01 CD	2.03±0.59 BC
SD × T				
Before storage	105.50±5.57 ghi	22.00±3.16 b	64.00±6.47 gh	4.00±0.27 b
Day 7×Control	150.30±10.47 efg	21.80±1.12 b	103.70±10.74 cde	3.60±0.16 bc
Day 14×Control	254.00±35.10 b	21.90±2.03 b	65.00±10.24 gh	5.30±0.14 a
Day 21×Control	122.80±22.58 f-i	20.70±2.14 b	60.60±5.56 h	1.20±0.04 hi
Day 7×0.5 mM PUT	87.90±10.08 i	20.60±0.40 b	111.90±11.24 bcd	3.00±0.25 de
Day 14×0.5 mM PUT	95.20±5.41 i	20.40±0.41 b	104.00±10.47 cde	3.10±0.26 de
Day 21×0.5 mM PUT	92.50±8.78 i	20.90±0.91 b	95.00±4.08 c-g	2.80±0.13 e
Day 7×1.0 mM PUT	190.53±10.10 cde	24.80±2.08 ab	115.60±15.12 bcd	3.60±0.27 bc
Day 14×1.0 mM PUT	200.33±14.91 cd	24.80±3.04 ab	120.38±19.83 bc	3.40±0.18 cd
Day 21×1.0 mM PUT	215.40±15.35 bc	24.20±1.24 ab	100.43±10.10 c-f	3.20±0.05 cde
Day 7×0.5 mM CA	334.70±30.20 a	24.80±3.10 ab	158.30±10.20 a	0.80±0.21 i
Day 14×0.5 mM CA	320.50±20.10 a	24.60±1.22 ab	142.00±16.23 ab	1.20±0.12 hi
Day 21×0.5 mM CA	185.00±15.02 cde	23.40±2.02 ab	137.00±10.05 ab	1.30±0.05 gh
Day 7×1.0 mM CA	175.30±10.31 cde	23.90±2.25 ab	85.00±5.47 d-h	1.60±0.05 fgh
Day 14×1.0 mM CA	163.90±10.21 def	23.60±3.14 ab	71.20±5.12 fgh	1.70±0.14 fg
Day 21×1.0 mM CA	154.60±10.05 d-g	23.50±0.52 ab	75.00±6.24 e-h	1.80±0.03 f
Day 7×0.5 mM SA	125.10±5.68 f-i	23.50±1.04 ab	61.80±5.06 h	1.40±0.15 fgh
Day 14×0.5 mM SA	145.60±20.12 e-h	23.40±0.40 ab	65.40±4.36 gh	1.50±0.15 fgh
Day 21×0.5 mM SA	150.60±10.70 efg	23.60±0.62 ab	66.00±6.45 gh	1.60±0.15 fgh
Day 7×1.0 mM SA	99.50±9.24 hi	28.10±2.56 a	114.80±14.21 bcd	2.80±0.21 e
Day 14×1.0 mM SA	177.10±5.42 cde	22.40±1.74 ab	62.60±8.08 h	1.60±0.10 fgh
Day 21×1.0 mM SA	110.50±10.68 ghi	24.10±3.45 ab	75.50±5.09 e-h	1.70±0.15 fg
Significant effects (P values)				
SD	0.0556	0.3790	0.0330	0.0205
T	0.0001	0.0001	0.0001	0.0001
SD × T	0.0001	0.0039	0.0001	0.0001

PUT: Putrescine; CA: Citric acid; SA: Salicylic acid; Fe: Iron, Mn: Manganese, Zn: Zinc; Cu: Copper; ±: Standard deviation of mean; ns: non-significant.

Among the treatments, 0.5 mM CA treatment had the highest Fe content, while the lowest Fe content was recorded in 0.5 mM PUT. Regarding storage duration × treatment interaction, it was found that the highest Fe content (334.70 mg kg^{-1}) was detected in Day 7×0.5 mM CA treatment. However, the lowest Fe content (87.90 mg kg^{-1}) was observed in Day 7×0.5 mM PUT treatment. When the effect of treatments on Mn content was examined, the highest values were detected in 1.0 mM PUT and 1.0 mM SA, though the lowest value was recorded in 0.5 mM PUT treatment. The higher values in terms of Mn content were obtained from all treatments except 0.5 mM PUT compared to the control. Depending on different storage durations and treatments discussed in the study, Mn content varied from 20.40 (Day 14×0.5 mM PUT) to 28.10 mg kg^{-1} (Day 7×1.0 mM SA). The Zn content of cauliflower increased after storage compared with before storage.

As the storage duration increased, Zn content decreased. The zinc content on the 7th day was found to be the highest. Among the treatments, maximum Zn content was detected in 0.5 mM CA, whereas minimum Zn contents were observed in control, 1.0 mM CA and 0.5 mM SA. It was found that the higher values in terms of Zn content were obtained from all treatments except 0.5 mM SA compared to the control. It was determined that 0.5 mM CA treatment increased Zn content by 90.72% compared with the control. In the present study, Zn content differed significantly according to different storage durations and treatments. Zn content varied between 60.60 and 158.30 mg kg^{-1}. Compared with before storage, Cu content decreased significantly after storage. The Cu content on the 21st day was found to be the lowest. When the effect of treatments on Cu content was examined, the highest values were found in control and 1.0 mM PUT, though the lowest values were recorded in 0.5 mM CA, 1.0 mM CA and 0.5 mM SA treatments. Cu content ranged from 0.80 to 5.30 mg kg^{-1} depending on storage duration × treatment interaction.

One of the most important features that increase the nutritional value of vegetables is their high protein content. Kibar et al. (2023) reported that the effect of storage durations (7, 14 and 21 days) on protein content of broccoli stored at 4 °C for 21 days was found to be insignificant, and SA, CA and PUT applications increased protein content compared to the control. In terms of protein content in *Pleurotus ostreatus* mushroom stored at 4 °C for 14 days, generally higher values were obtained from PUT, SA and CA applications compared to the control. It was also reported that the effect of storage time on protein content was insignificant (Şahin, 2022). Our findings are similar to the results of Şahin (2022). In the study conducted on *Agaricus bisporus* mushroom by Motamedi et al. (2020), it was determined that PUT and CA applications increased protein content compared to the control. Therefore, the results obtained in this study are compatible with the findings of Motamedi et al. (2020). Contrary to our results, it was stated that postharvest CA application generally caused a decrease in protein content of *Cantharellus cibarius* mushroom stored at 0 °C for 12 days compared to the control (Ozturk et al., 2021).

Mineral element contents of vegetables may vary depending on post-harvest preservation methods. Little literature is available on changes in the mineral composition of cauliflower during postharvest storage. Cebula et al. (2006) reported that P, K, Ca, Mg and Fe contents of cauliflower stored at 2 °C for 5 weeks increased after storage compared to before storage. Kibar et al. (2023) found that SA, CA and PUT treatments increased P, Mg and Ca contents of broccoli stored at 4 °C for 21 days, and decreased K content compared to the control. Researchers also reported that the effect of storage durations (7, 14 and 21 days) on K, Mg and Ca contents was insignificant. In the study conducted on *Agaricus bisporus* mushroom by Motamedi et al. (2020), it was determined that PUT and CA applications significantly affected the macro and micro element contents of the mushroom. Researchers reported that polyamine treatments cause an increase in nutritional value. It was also stated that the increased uptake of nitrogen, phosphorus and potassium minerals with polyamine application may be because polyamines play a role in many biochemical and physiological processes. In another study, it was reported that postharvest PUT treatment in cucumber caused a delay in ageing and was a promising method for preserving postharvest quality (Jia et al., 2018). Üner (2021) stated that postharvest SA application in parsley helped maintain quality. The results obtained in this study are generally compatible with the findings reported in previous studies. The effectiveness of postharvest chemical applications may vary depending on species, variety, application dose, storage conditions and laboratory conditions (Horvath et al., 2007; Assar et al., 2012).

Changes in Color Properties

According to statistical analysis results, significant differences were observed among storage durations with regards to all color values examined. There were statistically significant differences among treatments for a* and Hue angle values, while no statistically significant difference was found among treatments in terms of L*, b* and Chroma values. When the interaction between storage durations and treatments was examined, it was found to be significant for L*, a* and Hue angle values. On the other hand, storage duration × treatment interaction in terms of b* and *Chroma* values were found to be statistically insignificant (Table 4).

Table 4. Effect of putrescine, citric acid and salicylic acid on color properties of fresh-cut cauliflower during storage at 4 °C.

Çizelge 4. 4 °C'de muhafaza süresince taze kesilmiş karnabaharın renk özellikleri üzerine putresin, sitrik asit ve salisilik asidin etkisi.

Storage duration (SD)	L*	a*	b*	Chroma	Hue angle
Before storage	81.30±1.41 A	3.61±0.59 B	20.46±2.28 A	20.77±2.34 A	79.93±1.06 A
Day 7	78.65±8.03 AB	3.93±1.13 B	19.29±2.41 AB	19.82±2.38 AB	78.54±2.88 A
Day14	76.49±8.54 B	5.01±1.64 A	19.31±2.75AB	19.99±2.94A	75.59±3.51 B
Day 21	80.99±1.93 A	3.57±0.54 B	17.98±1.44 C	18.50±1.51 B	78.88±0.99 A
Treatment (T)					
Before storage	81.30±1.41 ns	3.61±0.59 B	20.46±2.28 ns	20.77±2.34 ns	79.93±1.06 A
Control	79.46±2.72 ns	3.78±0.79 B	18.68±2.06 ns	19.27±2.08 ns	78.63±1.45 AB
0.5 mM PUT	77.09±6.06 ns	5.00±1.28 A	19.83±2.57 ns	20.52±2.96 ns	76.23±4.57 C
1.0 mM PUT	75.68±11.79 ns	4.49±1.25 AB	19.02±2.87 ns	19.58±2.87 ns	76.63±3.90 C
0.5 mM CA	81.23±2.29 ns	3.70±0.95 B	18.20±1.77 ns	18.58±1.91 ns	78.58±1.86 AB
1.0 mM CA	79.43±2.30 ns	4.24±0.92 AB	19.43±1.81 ns	20.09±1.78 ns	77.90±1.69 B
0.5 mM SA	77.22±11.69 ns	4.37±1.22 AB	18.91±3.11 ns	19.70±2.96 ns	76.94±3.33 C
1.0 mM SA	80.88±3.12 ns	3.61±0.96 B	17.97±1.56 ns	18.34±1.68 ns	78.79±2.42 AB
SD × T					
Before storage	81.30±1.41 a	3.61±0.59 b	20.46±2.28 ns	20.77±2.34 ns	79.93±1.06 a
Day 7×Control	79.23±3.10 ab	3.73±0.54 b	19.53±1.89 ns	19.88±1.95 ns	79.23±0.54 a
Day 14×Control	78.66±3.01 ab	4.42±0.90 ab	18.89±2.90 ns	19.40±3.02 ns	76.92±0.96 abc
Day 21×Control	80.48±2.25 a	3.19±0.35 b	17.63±0.77 ns	18.52±1.02 ns	79.75±0.69 a
Day 7×0.5 mM PUT	78.17±4.29 ab	4.58±1.85 ab	20.11±2.62 ns	20.65±2.98 ns	77.49±3.17 abc
Day 14×0.5 mM PUT	72.30±7.65 ab	6.54±1.91 a	20.60±3.54 ns	21.73±4.00 ns	72.80±6.31 bc
Day 21×0.5 mM PUT	80.79±2.08 a	3.87±0.53 b	18.77±1.19 ns	19.17±1.27 ns	78.38±0.93 ab
Day 7×1.0 mM PUT	79.91±0.60 ab	4.54±0.42 ab	21.62±1.45 ns	22.09±1.50 ns	78.15±0.43 ab
Day 14×1.0 mM PUT	65.42±6.63 b	5.71±0.97 ab	17.99±3.20 ns	18.90±3.15 ns	72.10±3.42 c
Day 21×1.0 mM PUT	81.72±3.15 a	3.21±0.67 b	17.45±1.92 ns	17.75±1.99 ns	79.64±1.25 a
Day 7×0.5 mM CA	81.70±2.92 a	3.20±0.44 b	18.17±1.09 ns	18.45±1.15 ns	79.93±0.92 a
Day 14×0.5 mM CA	80.22±2.72 a	4.28±1.38 ab	19.01±2.55 ns	19.50±2.76 ns	77.53±2.57 abc
Day 21×0.5 mM CA	81.77±0.68 a	3.63±0.55 b	17.41±1.30 ns	17.79±1.38 ns	78.26±0.95 ab
Day 7×1.0 mM CA	79.82±1.51 ab	3.59±0.15 b	18.74±0.66 ns	19.08±0.65 ns	79.16±0.59 a
Day 14×1.0 mM CA	77.54±2.54 ab	5.11±1.14 ab	20.36±2.37 ns	20.99±2.56 ns	76.05±1.67 abc
Day 21×1.0 mM CA	80.92±1.54 a	4.02±0.31 ab	19.18±1.92 ns	20.18±1.34 ns	78.51±0.44 a
Day 7×0.5 mM SA	71.57±7.14 ab	4.64±1.34 ab	19.07±4.34 ns	20.48±3.48 ns	75.90±5.42 abc
Day 14×0.5 mM SA	79.15±2.20 ab	4.97±1.33 ab	19.97±3.28 ns	20.59±3.49 ns	76.06±1.49 abc
Day 21×0.5 mM SA	80.94±2.39 a	3.49±0.37 b	17.69±1.02 ns	18.04±1.06 ns	78.84±0.65 a
Day 7×1.0 mM SA	80.13±4.61 ab	3.25±1.35 b	17.80±2.01 ns	18.12±2.17 ns	79.94±3.60 a
Day 14×1.0 mM SA	82.15±2.90 a	4.04±0.82 ab	18.38±1.55 ns	18.82±1.66 ns	77.68±1.72 abc
Day 21×1.0 mM SA	80.35±1.17 a	3.54±0.58 b	17.73±1.31 ns	18.08±1.39 ns	78.75±1.15 a
Significant effects (P values)					
SD	0.0410	0.0001	0.0199	0.0227	0.0001
T	0.2599	0.0426	0.2403	0.1464	0.0482
SD × T	0.0100	0.0001	0.1540	0.0762	0.0001

PUT: Putrescine; CA: Citric acid; SA: Salicylic acid; ±: Standard deviation of mean; ns: non-significant.

When the color properties of cauliflower was examined, L*, b*, Chroma and Hue angle values decreased significantly after storage compared to before storage. The highest L* value was determined on the 21st day, while the lowest L* value was observed on the 14th day. The highest a* and Chroma values were detected on the 14th day. On the other hand, the lowest b* and Chroma values were found on the 21st day. The highest Hue angle value was detected on the 7th and 21st days, whereas the lowest Hue angle value was recorded on the 14th day. Among the treatments, the highest a* value was detected in 0.5 mM PUT. However, the lowest a* values were observed in control, 0.5 mM CA and 1.0 mM SA treatments. The

highest values with regard to Hue angle were found in control, 0.5 mM CA and 1.0 mM SA treatments, though the lowest values were observed in 0.5 mM PUT, 1.0 mM PUT and 0.5 mM SA treatments. The color properties of cauliflower (except for b* and Chroma values) considerably changed depending on storage duration × treatment interaction. The L*, a*, b*, Chroma and Hue angle values ranged from 65.42 to 82.15, 3.19 to 6.54, 17.41 to 21.62, 17.75 to 22.09 and 72.10 to 79.94, respectively.

Color is one of the most important sensory properties affecting the quality of cauliflower. Accordingly, the color of cauliflower is an important criterion in consumer preference. However, fresh-cut cauliflower will brown and rot during postharvest storage, which visually manifests as a color change (Liu et al., 2020). Changes in color during the processing and storage of cauliflower need to be measured and controlled. Browning of curd is a result of enzymatic browning due to polyphenol oxidase enzyme activity (PPO) (Brown, 2003). The change in color of cauliflower can be explained by ethylene production (Simon et al., 2008). Because, this vegetable is extremely sensitive to ethylene (Suslow and Cantwell, 1999). Kasim and Kasim (2017) reported that the L* value of fresh-cut cauliflower stored for 28 days at 4 °C decreased at the end of the storage period compared to before storage. Additionally, it was stated that L* and Hue angle values fluctuated during storage. Nasrin et al. (2022) found that L*, Chroma and Hue angle values of fresh-cut cauliflower decreased during storage (20 days at 4 °C) and also compared to before storage. In another study, the L* value of cauliflower decreased during 28 days of storage at 0±1°C, while the b* value increased (Dhall et al., 2010). Mu et al. (2022) reported that the L* value of fresh-cut cauliflower decreased during storage (15 days at 4 °C), while a* and b* values increased. Researchers also found that the L* value decreased compared to before storage, while the a* and b* values increased. In minimally processed cauliflower stored at 4 °C for 21 days, L* and a* values decreased compared to before storage, and b* and Chroma values increased (Miceli et al., 2015). Raseetha and Nadirah (2018) reported that the L* and b* values of fresh-cut cauliflower increased during storage (21 days at 8-10 °C) and also compared to before storage, while a* value decreased.

Kibar et al. (2023) reported that the effect of SA, CA and PUT treatments on color values (L*, a*, b*, Chroma and Hue angle) of broccoli was found to be insignificant. Researchers also stated that as storage time increased, L*, b* and Chroma values increased, while a* value decreased. In the study conducted on cucumber by Jia et al. (2018), no significant difference was found between the control and PUT application in terms of L* and Hue angle color values at the end of the storage period. It was also detected that color was positively affected by the PUT application. The L* value of *Agaricus bisporus* mushroom in CA application at the end of the storage period was found to be higher than the control (Brennan et al., 2000). In the study conducted by Gupta and Bhat (2016) on *Agaricus bisporus* mushroom, it was found that the darkening of the mushrooms was significantly reduced with CA. It has been reported that CA has inhibitory activity on polyphenol oxidase (PPO) and anti-browning activity in processed fruits and vegetables (Ahvenainen, 1996). Dokhanieh and Aghdam (2016) determined that postharvest SA application in *Agaricus bisporus* mushroom delayed the darkening of the mushroom. It was stated that SA increased the antioxidant activity and accumulation of phenols and was beneficial in reducing post-harvest browning by preserving cell membrane integrity.

CONCLUSION

This study revealed the effect of exogenous PUT, CA and SA treatments on the postharvest quality of fresh-cut cauliflower during cold storage. The results of the study indicated that WL and ash content significantly increased with the increase of storage duration, while K, Zn and Cu contents decreased. Compared to the control, all treatments in the study except for 0.5 mM SA significantly reduced WL. The lowest WL was observed in 1.0 mM PUT treatment with 1.06% and it reduced WL by 61.32% compared with the control. Moreover, the highest values in terms of protein, ash, P, K and Mn contents were detected in 1.0 mM PUT treatment. Compared with the control, 0.5 mM CA treatment increased Zn content by 90.72%, and 1.0 mM SA treatment increased Mg and Ca contents by 13.38% and 22.46%, respectively. It was determined that the treatments investigated in the study had the potential to be used in extending the storage period and reducing quality losses of fresh-cut cauliflower. Additionally, 1.0 mM PUT was the most effective treatment. As a result, especially 1.0 mM PUT can be recommended as a promising application to maintain

the nutritional content of fresh-cut cauliflower, extend its storage life and reduce postharvest quality losses. The findings obtained in this study will contribute to the food industry by minimizing postharvest losses of fresh-cut cauliflower and provide potential information for future studies.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

DECLARATION OF AUTHOR CONTRIBUTION

BK: Design of the study, writing of the manuscript. HK: Design of the study, statistical analysis, writing of the manuscript. EG: Carrying out of the experiment, performing of laboratory studies.

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