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Effect of some Postharvest Treatments on Quality and Storability of Lettuce during Cold Storage

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Abstract

Lettuce heads (*Lactuca sativa* L.) cv. Iceberg were harvested at a suitable maturity stage of marketing in the 2024 and 2025 seasons to study the impact of some postharvest treatments [chitosan (CS) at 1% and carboxymethyl cellulose (CMC) at 1% separately and each of them in combination with L-cysteine (L-Cys) at 1% and ascorbic acid (AsA) at 5%], besides an untreated control (spray with distilled water), on preserving quality and enhancing storability of lettuce heads during storage at 0°C and 95% relative humidity for 16 days. The obtained results revealed that all postharvest treatments were the most effective treatments in preserving head quality attributes, controlling the discoloration of heads, and overall appearance of lettuce heads in comparison with untreated control. However, lettuce heads treated with CMC at 1% + L-Cys at 1% were the most effective treatment in lowering weight loss percentage, discoloration, phenylalanine ammonia-lyase activity, polyphenol oxidase activity, and maintained quality attributes (firmness, ascorbic acid content, TSS, and total phenols) and gave an excellent appearance after 16 days of storage at 0°C.

Keywords: Lettuce heads, Carboxymethyl cellulose, Chitosan, L-cysteine, Ascorbic acid, Quality, Cold storage.

Introduction

Lettuce is a crucial vegetable crop for local consumption and exportation (Mohammed et al., 2019). Lettuce plants are a highly perishable crop after harvest because of their high moisture content, short life, high respiration rate, and shriveling linked to quick weight loss. The main reasons why lettuce plants lose quality include dehydration, leaf discoloration, and decay (Bardisi et al., 2013). Major problems of leaves and cut stem lettuce during storage are highly susceptible to enzymatic browning. The major step of enzymatic browning is the oxidation of phenolic compounds by PPO when oxygen is present (Xylia et al., 2021), therefore resulting in economic loss to the producer and generally causing loss of nutritional, functional and organoleptic qualities and decreasing their visual quality and marketability (Martin-Diana et al., 2005). Therefore, it is very crucial to prevent these reactions by using some postharvest treatments such as chitosan, carboxymethyl cellulose, L-cysteine and ascorbic acid.

The edible coating is mostly composed of proteins, lipids, or polysaccharides that can create a thin layer on food's surface to prevent mechanical damage, tissue dehydration, microbial invasion, softening and browning (Aparicio-García et al., 2021), and also maintain the appearance and storage quality of fruit (Han et al., 2004 and Chen et al., 2019). The use of polysaccharide-based edible coatings, which are enriched with antioxidants or antimicrobials, has been confirmed to have great potential for creating high quality and long shelf-life products (Li et al., 2017).

Chitosan (CS) is a natural, nontoxic in a range of toxicity tests, safe, biocompatible, and biodegradable natural alkaline polysaccharide derived from the de-acetylation of chitin (Carlson et al., 2008). CS

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coating treatment delayed senescence, which is due to inhibition of respiration rate, improved the antioxidant system, and raised the activities of antioxidant enzymes (Zhang et al., 2019). Li et al. (2021) revealed that CS coating significantly delayed browning, preserved appearance, and slowed down senescence of fresh-cut lettuce. Also, inhibiting the activities of the PPO and PAL to decrease phenolic metabolism and slow down reactions of enzymatic browning, alleviating membrane oxidative damage, maintaining quality, reducing water loss (Zahoorullah et al., 2017), and controlling microbial growth (Mahmoud et al., 2017).

Carboxymethyl cellulose (CMC) is a long linear chain, water-soluble, anionic polysaccharide (Hattori et al., 2004). CMC is a cellulose derivative. It has numerous functions as an edible coating for vegetables to delay dehydration, moisture loss, exchanges of carbon dioxide and oxygen, reduce respiration, weight loss%, decay, and discoloration as well as preserve the total phenolic content and total chlorophyll of the product during storage (Hussein et al., 2020). Thus, it can increase the fresh fruits' shelf life during transportation and storage before consumption (Lee et al., 2003).

Ascorbic acid (AsA) is a natural antioxidant that helps in preserving the postharvest quality of horticultural crops due to its anti-pathogenic actions (Jayachandran et al., 2007; Bilgin and Aslantaş, 2022), retained greater firmness (Lin et al., 2008), preventing pericarp browning, dehydration, and microbial attack (Sun et al., 2010), delaying the increase of weight loss, preserving the quality attributes and enhancing the shelf life of lettuce (Xylia et al., 2021) and maintaining the bright green color of lettuce (Rivera et al., 2006). It is effective at removing free radicals (Kapoor et al., 2022). AsA used to prevent enzyme-catalyzed browning reactions by reducing the oxidation of phenolic compounds (Mubo et al., 2019). Xylia et al. (2021) stated that AsA raised total phenolic and antioxidant levels of lettuce, and reduced enzyme activity related to the browning of plant tissue (i.e., polyphenol oxidase and peroxidase activity). The application of AsA combined with a suitable type of coating, like CS and CMC might be considered more appropriate for controlling overall produce quality and minimizing browning (Saba and Sogvar, 2016).

L-Cysteine (L-Cys) is one of the most effective agents of anti-browning which is widely used alone or combined with different coatings and organic acid in harvested horticultural crops (Pace et al., 2015 and Li et al., 2018). L-Cys at 0.5% conserved the quality and prolonged the shelf life of lettuce heads. L-Cys significantly reduced weight loss, decay, and discoloration, maintained ascorbic acid content and total chlorophyll, delayed the activity of polyphenol oxidase, reduced the loss of total phenolic contents in lettuce, showed the best appearance after 20 days of storage (Abdullah et al., 2023) and prevented of postharvest senescence of green leafy vegetables (Ubeed et al., 2019).

L-Cys at (0.1%) efficiently decreased respiration activity and, the browning process, maintained the antioxidant activity of fresh cut lettuce (Pace et al., 2015) and controlled microbial growth (Alvarez et al., 2012). L-Cys significantly raised the contents of total phenols, total flavonoids and flavanols, retarded the rise of relative electric conductivity, MDA, POD, and PPO activities, and significantly improved the activities of SOD and CAT, and DPPH free radical scavenging ability, all of which improved antioxidant capacity (Zhang et al., 2023).

The use of CS + AsA increased total phenolic and antioxidant levels, and decreased yeasts and molds of fresh-cut lettuce during the storage (Xylia et al., 2021), maintained the postharvest quality of papaya and reduced weight loss, as well as prevented of the activity of softening enzyme and gene expression level. Also, CS + AsA reduced the browning process and delayed senescence (Zhou et al., 2022).

The aim of the current study was to assess the efficacy of carboxymethyl cellulose, chitosan, ascorbic acid, cysteine, and different combinations of them in the preservation of quality-related attributes and prevention of the browning of head lettuce during storage at 0 °C.

Materials and Methods

Lettuce heads (*Lactuca sativa* L.) cv. Iceberg were harvested at a suitable maturity stage of marketing on January 16th and 14th in the 2024 and 2025 seasons, respectively, from a private farm in Fayed district, Ismailia Governorate. The uncompact and non-uniform heads were eliminated and only healthy, undamaged darker green outer leaves, symmetrical in shape, compact and firm were chosen and transported immediately to the Laboratory of Postharvest and Handling of Vegetable Crops Department, Horticulture Research Institute, Agriculture Research Center, Giza, Egypt. The dry and damaged outer leaves were removed, and the stems of head lettuce were cut by a sharp knife (1 cm in length). Lettuce heads were sprayed with a solution of chitosan (CS) at 1% and carboxymethyl cellulose (CMC) at 1% separately and each of them in combination with L-cysteine (L-Cys) at 1% and ascorbic acid (AsA) at 5%, besides the untreated control (spray with distilled water).

After treatments, the heads were left until drying for 2 h at room temperature. Every head was wrapped individually in a polypropylene bag (30 µm thickness) and served as one replicate. Fifteen replicates from each treatment were prepared and three lettuce heads (3 replicates) were placed in carton boxes (30×20×15cm) and stored at 0°C and 95% RH for 16 days. The treatments were arranged

in a completely randomized design with three replicates. Measurements were recorded immediately after harvest and every 4 day-intervals to determine the following parameters:

- **Weight loss:** Loss in weight percentage calculated by the following equation: Loss in weight % = (Initial weight of head – weight of head at sampling date) / the initial weight of the head × 100.
- **General appearance:** The appearance was evaluated using a scale from (1 to 9) where 9 = excellent, 7 = good, 5 = fair and 3= poor. Heads rating (5) or below were considered unmarketable. The general appearance assessment includes symptoms of deterioration (leaf dryness, leaf wilt and yellowing, browning in the cut stem surface and decay).
- **Discoloration:** Discoloration was evaluated on a scale of 1 to 5 where 1 = none, 2 = slight, 3 = moderate, 4 = severe and 5 = extra severe.
- **Color:** External surface color was evaluated by a color meter (Minolta CR 200) to measure the lightness (L* value) and hue angle (h°) value for lettuce heads.
- **Firmness:** Lettuce head firmness was recorded by a TA- 1000 texture analyzer instrument using a penetrating cylinder of 1 mm diameter, to a constant distance (3 and 5 mm) inside the pulp of the heads and by a constant speed of 2 mm per second.
- **Ascorbic acid content (as indicated for vit. C):** vit. C was determined by titration method using 2, 6-dichloro-phenol indophenols as described in AOAC (2000).
- **Total soluble solids percentage (TSS):** TSS was determined as a composite juice sample by digital refractometer, "Model Abbe Leica" according to AOAC (2000).
- **Total phenolic compounds (TPC):** TPC content was determined by the colorimetric modified method of Velioglu *et al*. (1998) using Folin-Ciocalteu reagent.
- **Phenylalanine ammonia-lyase (PAL) activity**: Phenylalanine ammonia-lyase (PAL; EC 4.3.1.5) activity was measured in the protein extract as previously described by Ke and Saltveit (1989) with slight modification by Campos-Vargas et al. (2005).
- **Polyphenol oxidase (PPO) activity:** Polyphenol oxidase activity was determined by the colorimetric modified method of Dogăn et al. (2002).

Statistical Analysis

Data were statistically analysed using the analysis of variance described by Snedecor and Cochran (1980). The method of Duncan multiple range test was applied for the comparison between means according to Waller and Duncan (1969).

Results and Discussion

Weight Loss

Data in Table (1) reveal that there were significant rises in weight loss percentage with the prolongation of storage period during both seasons. Similar outcomes were attained by Abdullah et al. (2023**)** and possibly because of the loss of dry matter through the respiration process and the water loss via transpiration and other senescence linked to metabolic processes during storage (Bilgin and Aslantaş, 2022).

All treatments reduced weight loss in comparison with the untreated control. After 16 days of storage, lettuce heads sprayed with a solution of CMC 1% + L-Cys 1% or CS 1% + L-Cys 1% were the most effective treatments in reducing weight loss % during the storage with significant differences between them in both seasons, followed by CMC 1% + AsA 5%. CMC 1% or CS 1% was less effective in this concern, whereas the untreated control showed the greatest percentage of weight loss. These outcomes were achieved in both seasons and agreed with Hussein et al. (2020), Xylia et al. (2021) and Zhang et al. (2023).

Chitosan and CMC coating decreased weight loss during the storage as it enabled epidermal tissues to control water loss and lower respiratory activity, and provided a barrier against water vapor, minimizing moisture loss and retarding fruit dehydrations (Tzoumaki et al., 2009, Qiu et al., 2013 and Shiri et al., 2013). AsA and CS treatments prevented water loss and retarded the ripening and senescence of papaya fruits, resulting in reduced weight loss (Ghosh et al., 2021). Lettuce treated with AsA or L-Cys reduced senescence and metabolic activity in lettuce tissues, thus reducing weight loss (Pace et al., 2015).

General Appearance

Data in Table (2) reveal that the general appearance (score) of lettuce heads reduced with the extension of the storage period. These outcomes agreed with Abdullah et al. (2023). The decrease in GA of lettuce heads during storage could be because of morphological defects, like cut surface dryness, discoloration, wilting, shriveling, or macroscopic decay (Shehata et al., 2012).

All treatments had significantly the greatest score of appearance in comparison with the untreated control. After 16 days of storage, data showed that lettuce heads sprayed with CMC 1% + L-Cys 1% or CS 1% + L-Cys 1% did not exhibit any changes in

general appearance till 16 days of storage at 0°C and gave an excellent appearance. While CMC 1% + AsA 5% or CS 1% + AsA 5% treatments rated a good appearance in the same period. However, untreated heads had a poor appearance after 16 days of storage at 0°C. These outcomes were achieved in both seasons and agree with Hussein et al. (2020), Xylia et al. (2021) and Abdullah et al. (2023).

It's possible that the application of CS or CMC preserves visual quality by reducing weight loss, respiratory activity, enzyme degradation, and microbial rot of the fruits, preventing fruit dehydration and shrinkage, and preserving overall quality (Ansorena et al., 2011; Helaly et al., 2016 and Miran & Javanmard, 2016). Furthermore, previous works revealed the positive effect of L-Cys for inhibiting the browning development, delaying fruit senescence and reducing microbial growth and decay in fresh-cut lettuce during the cold storage (Salemi et al., 2021). Likewise, AsA has the ability to prolong storage life by lowering water loss (Nazoori et al., 2020), caused a reduction in pH which is not appropriate for microbial growth (Xylia et al., 2021), inhibiting pericarp browning, dehydration, and microbial attack, as well as preserving membrane integrity (Sun et al., 2010) therefore maintaining fruit quality attributes.

Discoloration

The results in Table (3) demonstrate that the discoloration (score) increased for lettuce as the period of storage prolonged. These outcomes agree with Abdullah et al. (2023). The color change is mostly connected to the oxidation of phenolic compounds to o-quinones by polyphenol oxidase (PPO) in the presence of oxygen. Quinones can polymerize dark brown, black or red polymers (Hussein *et al*., 2020).

All coating treatments decreased the incidence of discoloration in comparison to untreated heads. After 16 days of storage, lettuce heads sprayed with CMC 1% + L-Cys 1%, CS 1% + L-Cys 1% or CMC 1% + AsA 5% prevented discoloration in lettuce and had fewer scores of discoloration with no significant differences between them, followed by CS 1% + AsA 5%, while CMC 1% or CS 1% alone treatments were less effective in this concern. Conversely, the untreated control exhibited the highest discoloration score and resulted in severe discoloration at the end of storage. These outcomes agree with Hussein et al. (2020) who discovered that broccoli florets coated with CS or CMC did not significantly alter their initial color and were effective for preventing enzymatic browning and obtaining good color. This prevention of enzymatic browning was linked to the inhibition of PPO enzyme activity (Vickers et al., 2005). Therefore, CS or CMC treatments have an inhibitory effect against any changes that might happen in color (Ansorena et al., 2011, Xylia et al., 2021 and Abdullah et al., 2023).

L-Cys can significantly slow the browning of fresh-cut lettuce by decreasing pH, preventing PPO and POD activity, and oxidation of polyphenol, and greatly improve antioxidant capacity (Pace et al., 2015). Also, L-Cys will react with quinone and give a stable and colorless compound (Ali et al., 2019). The decreased browning in lettuce induced by AsA treatment is due to its role in reducing polyphenol oxidase activity (Landi et al., 2013).

Color [lightness (L* Value)]

During storage, variations in lightness (L* value) were noted in comparison to the initial value. The lightness of lettuce head was impacted by storage time. By extending the storage time, a decrease in the L* value was observed Table (4), resulting in a darker color. These findings were obtained in both seasons and agree with Abdullah et al. (2023). The decrease in L* color during storage might be in connection with the surface dehydration which reduces the glossiness of the surface (Perdones et al., 2016).

After 16 days of storage, data revealed that there were significant differences between postharvest treatments. Lettuce heads sprayed with CMC 1% + L-Cys 1% or CS 1% + L-Cys 1% being the most effective treatments in preserving the L* values, led to lighter color (high L* value) with significant differences between them in the two seasons, whereas the untreated control gave the least one of L* values during storage, led to darker color. The other treatments were less effective in this concern. These results agreed with Hussein et al. (2020), Xylia et al. (2021), Zhou et al. (2022), Abdullah et al. (2023), and Saba et al. (2023). The use of CS as an edible coating on fruit surface could provide an additional gloss on fruit surface which increases and conserves the L* value during storage (Baldwin et al., 2011). Also, CS assists in forming a thin protective layer on lettuce's surface to lessen water transmission (Li et al., 2021).

Saba et al. (2023) showed that CMC 1% combined with AsA 2% treatment maintained the color of fresh-cut apple by reducing enzymatic browning and raising the antioxidant impact of ascorbic acid which are some of the potential reasons for retaining the color of freshly cut samples during storage. Maintaining the L* value by using L-Cys treatment might be due to the function of L-Cys in reducing the browning of lettuce (Abdullah et al., 2023).

Color (Hue angle)

Data in Table (5) show that the hue angle value of lettuce heads gradually reduced as the storage period extended (turned to slight yellow as the storage period extended). These findings agree with Xylia et al. (2021).

All treatments had significantly greater hue angle values in comparison with the untreated control. After 16 days at 0°C, data showed that lettuce heads sprayed with CMC 1% + L-Cys 1% or CS 1% + L-Cys 1% were the most effective treatments in decreasing the loss of hue angle and showed the greatest value of hue angle (showed more green color), while untreated heads (control) gave the least value of hue angle at the end of the storage period (indicated less green color or minimal green color). These results agree with Hussein et al. (2020), Xylia et al. (2021) and Zhou et al. (2022).

Firmness

Data in Table (6) reveal that the firmness of the lettuce head decreased continuously with the prolongation of the storage period. The loss of fruit firmness is one factor that decreases the quality of fruits after the harvest by the polymerization and destruction of cell wall compounds. The activity of pectin methylesterase (PME) and polygalacturonase (PG) results in cell wall degradation. Pectin changes into low methyl pectin or pectin acid by PME and PG is responsible for decreasing the molecular weight of polymers and reducing the fruit firmness by hydrolyzing the glycosidic linkages of the pectin substance (Yildiz and Baysal, 2006). Additionally, the breakdown of the middle lamella of cortical parenchyma cells has been connected to softening alterations, leading to a significant rise in pectin solubilization (García et al., 2014).

At the end of storage, data showed that different applied treatments gave significantly higher firmness of lettuce heads than untreated control during storage in the two seasons. Lettuce heads sprayed with a solution of CMC 1% + L-Cys 1% or CS 1% + L-Cys 1% and CMC 1% + AsA 5% or CS 1% + AsA 5% were the most effective treatments in reducing the loss of firmness during storage with no significant differences between them in both seasons. However, CMC 1% or CS 1% alone was less effective in this concern. The least value of firmness was found in the untreated control. These outcomes agreed with Atala et al. (2019), Gohari et al. (2021) and Zhou et al. (2022).

The beneficial effect of methylcellulose and chitosan coating on firmness during storage is probably due to these materials delaying degradation of insoluble proto-pectins to the more soluble pectic acid and pectin (Tanada-Palmu & Grosso, 2005 and Saleem et al., 2021). Also, CS and CMC can reduce tissue's oxygen availability, which lowers the activity of the enzymes that cause firmness loss, like pectin-esterase and polygalacturonase, leading to greater firmness during storage (Hussein et al., 2020 and Hesami et al., 2021).

CS is a negatively charged polysaccharide that can form a chitosan–pectin complex with pectin and prevent pectinase (such as PG) from entering the substrate, ensuring that the cell wall is stronger (Gonz´alez-Aguilar et al., 2009). Applying AsA + CS to fruits may prevent the expression of genes and activity of cell wall-degrading enzymes such as CX, PG, PME, and β-GAL, which preserve the cohesiveness of cell wall polysaccharides (Zhou et al., 2022). So, reduced the loss of fruit firmness during storage (Saleem et al., 2020). Retaining higher fruit firmness in fruits treated with L-Cys may be linked to the decrease in PME and PG activity (Alandes et al., 2009). Also, L-Cys preserved the cell membrane's structure, as evidenced by decreased levels of malondialdehyde (MDA) accumulation and electrolyte leakage (Gohari et al., 2021).

Ascorbic Acid Content

Data in Table (7) reveal that ascorbic acid content of heads was significantly reduced with the extension of the storage period. Similar outcomes were attained by Abdullah et al. (2023). This decrease in AsA during storage might be because of the use of AsA in the respiration process (Hesami et al., 2021). Ascorbate oxidase activity, which encourages the oxidation of AsA to dehydroascorbic acid, might be attributed to the decline of ascorbic acid content in fruits (Oliveira et al., 2018).

After 16 days of storage, lettuce heads treated with CMC 1% + L-Cys 1% and CS 1% + L-Cys 1% led to greater ascorbic acid content with significant differences between them in the second season, whereas the untreated control gave the least ones in the same time. These outcomes were achieved in both seasons and agreed with Hussein et al. (2020), Xylia et al. (2021) and Abdullah et al. (2023).

Interestingly, the combination of AsA and CMC coating treatment preserved vitamin C levels during storage. This could be because coatings have low oxygen permeability, which lowers enzyme activity and inhibits AsA oxidation (Saba et al., 2023). The greater level of AsA in CS and L-Cys treated fruit could be a result of limited oxygen permeability, which slows down respiration rate, and retards the deteriorative oxidation reaction of the fruit's AsA (Dang et al., 2010) and thereby better preserves the ascorbic acid level and retards fruit senescence (Qiu et al., 2013 and Sogvar et al., 2020). AsA can decrease oxidative stress by the decomposition of H_2O_2 during the AsA-glutathione cycle (Singh et al., 2012). So, in our case, AsA and CS or CMC probably prevented AsA content decline in the treated heads because of prevented oxidation and retarded senescence.

Total Soluble Solids

Data in Table (8) reveal that total soluble solids of heads were significantly reduced with the extension of the storage period. Similar outcomes were obtained by Abdullah et al. (2023). The decrease in TSS might be associated with respiration

rate and the consumption of sugars throughout this process (Moreira et al., 2006).

All treatments gave significantly the greatest value of total soluble solids percentage in lettuce heads in comparison with untreated control. After 16 days of storage, lettuce heads sprayed with CMC 1% + L-Cys 1% or CS 1% + L-Cys 1% were the most effective treatments in preserving TSS and resulted in higher total soluble solids with no significant differences between them, whereas the untreated control gave the least ones in the same time. These outcomes were achieved in both seasons and agreed with Hussein et al. (2020), Xylia et al. (2021) and Abdullah et al. (2023).

The effect of CS or CMC treatments in preserving the total soluble solid contents was most likely caused by these materials delaying the ripening process by reducing metabolic activity and respiration and delaying the utilization of organic acids (Ali et al., 2011 and Hussein et al., 2020).

Total Phenolic Content

Data in Table (9) indicate that total phenolic content of lettuce heads reduced significantly with extending the storage period in both seasons. These findings agree with Abdullah et al. (2023) and probably because the PPO enzyme oxidized to produce the colored quinones, and PPO also directly oxidized quercetin (Queiroz et al., 2008). Additionally, Robards et al. (1999) discovered that phenolic compounds play important roles in oxidation processes as substrates for browning reactions and as antioxidants. The concurrent consumption of phenols and the development of blackness over the storage time can be explained by the continuation of enzymatic oxidation during storage, which results in the quinones being polymerized non-enzymatically to produce darker pigments.

All treatments gave significantly the highest value of total phenolic content in comparison with untreated heads. Additionally, lettuce heads sprayed with CMC 1% + L-Cys 1% and CS 1% + L-Cys 1% were the most effective treatments in preserving the phenolic content with significant differences between them, followed by CMC 1% + AsA 5% and CS 1% + AsA 5% treatments with no significant differences between them in both seasons. The least values of phenolic compounds were found in untreated control after 16 days of storage in both seasons. These outcomes agreed with Hussein et al. (2020), Xylia et al. (2021) and Abdullah et al. (2023) and possibly as a result of these materials decreased respiration rate which results in a reduction of metabolic activity and suppresses the activity of the enzymes during storage.

The major role of CS or CMC is strengthening the cell wall and stabilizing the cell membrane (Luna-Guzman and Barrett, 2000), thereby preventing the membrane-bound enzyme PPO from coming into contact with its phenolic substrates, which are mainly found in vacuoles, maintaining the phenolic content and preventing the browning process (Queiroz et al., 2008). Higher phenolic concentration in AsA or L-Cys treated lettuce heads was probably associated with their reduced oxidation. AsA or L-Cys treatments raised TP through reducing PAL, PPO, or both (Altunkaya and Gökmen, 2009).

Phenylalanine Ammonia-lyase (PAL) Activity

Data in Table (10) reveal that a significant rise was noticed in PAL activity of lettuce heads with the extension of storage period in both seasons. These outcomes agree with Rageh and Abou-Elwafa (2018).

Kang and Saltveit (2002) discovered that sustained wounding during the preparation of fresh cut caused PAL expression in lettuce tissue, which in turn led to the synthesis and accumulation of phenolic compounds, which are substrates for PPO, which aided in the tissue browning. Prevention of PPO and PAL activities is a crucial method to enhance the quality of fresh-cut vegetables during storage.

All treatments gave significantly the lowest active PAL enzyme in lettuce heads in comparison with untreated heads. After 16 days of storage at 0°C, lettuce heads sprayed with CMC 1% + L-Cys 1% or CS 1% + L-Cys 1% had significantly lower active PAL enzyme with a significant difference between them, followed by CMC 1% + AsA 5%, while the greatest ones were found in untreated heads. These findings agreed with Li et al. (2021) and Hussein et al. (2020).

Li et al. (2021) suggested that CS was the best polysaccharide-based edible coating for preventing PPO and PAL activity, lowering phenolic metabolism, and preserving a high total phenolic content to delay the browning of fresh-cut lettuce. CS at 1% increased SOD and POD, and at the same time decreased PPO and PAL activity during storage of cut lettuce.

Polyphenol Oxidase Activity (PPO)

Data in Table (11) indicate that PPO activity of lettuce heads rose with the extension of the storage period in both seasons. These findings agree with Abdullah et al. (2023). The rise of PPO activity during storage is mostly caused by the process of activation from a latent to a fully active state (Abdullah and Zakaria, 2024). Actually, according to earlier reports by Cantos et al. (2001) tissue wounding includes the breakdown of cellular components' metallization with the subsequent release of proteases including a cascade of reactions resulting in the activation of latent PPO.

All treatments decreased the PPO activity during storage in comparison with the untreated control. After 16 days of storage, lettuce heads sprayed with CMC 1% + L-Cys 1% and CS 1% + L-Cys 1% were the most effective treatments in delaying PPO activity during storage with significant differences between them in the first season, followed by CMC 1% + AsA 5%. However, CMC 1% or CS 1% alone was less effective in this concern, but the PPO enzyme activity increased more in the untreated control in both seasons. These outcomes agreed with Atala et al. (2019), Xylia et al. (2021) and Abdullah et al. (2023).

CMC most likely had an impact on enzyme activity by lessening stress conditions in fresh cuts. Regarding the mechanism of AsA, it has been shown that AsA could reduce oxidative stress on the fruit surface due to the antioxidant ability of AsA (Lamikanra and Watson, 2001) and thus controlled the activities of PPO and POX (Jang and Moon, 2011). The inhibiting impact of CS treatment on PPO activity is probably due to low O_2 availability, slown down respiration rate, which delays the activity of PPO (Qi et al., 2011).

CS films reduce the content of lipoxygenase (LOX) and malondialdehyde (MAD) enzymes, so they maintain the integrity of membrane, preserve the skin and flesh color and barriers between PPO and POD enzymes from their phenolic substrates. However, observed prevention of POD and PPO activities by CS films and enhanced postharvest shelf life of products (Zhang et al., 2015). Inhibiting PPO activity by L-Cys perhaps because of two reasons: decreasing o-quinines generation and the formation of stable-bound with copper that is in the active sites of PPO enzyme (Ali et al., 2019).

Conclusion

Regarding the previous results, it might be concluded that lettuce heads cv. Iceberg treated with CMC at 1% + L-Cys at 1% was the most effective treatment in decreasing weight loss percentage, discoloration, phenylalanine ammonia-lyase activity, polyphenol oxidase activity, and preserved quality attributes (firmness, ascorbic acid content, TSS, and total phenols) and gave excellent appearance of heads after 16 days of storage at 0°C.

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Not applicable.

Conflicts of interest

The author declares no conflict of interest.

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TABLE 1. Effect of some postharvest treatments and storage periods on weight loss percentage of lettuce heads during storage at 0°C in 2024 and 2025 seasons.

Treatments	2024 season					
	Storage periods (days)					
	0	4	8	12	16	Mean
Chitosan 1%	0.00 p	0.19 jk	0.26 hi	0.47 de	0.66 b	0.32 B
CMC 1%	0.00 p	0.16 k-m	0.23 ij	0.41 fg	0.58 c	0.28 C
Chitosan 1% + cysteine 1%	0.00 p	0.08 o	0.15 k-m	0.23 ij	0.36 g	0.16 F
CMC 1%+cysteine 1%	0.00 p	0.06 o	0.11 m-o	0.18 j-l	0.29 h	0.13 G
Chitosan 1%+ascorbic acid 5%	0.00 p	0.14 l-n	0.22 ij	0.37 g	0.48 d	0.24 D
CMC 1%+ascorbic acid 5%	0.00 p	0.10 no	0.18 j-l	0.29 h	0.42 ef	0.20 E
Control	0.00 p	0.25 hi	0.37 g	0.68 b	0.95 a	0.45 A
Mean	0.00 E	0.14 D	0.22 C	0.37 B	0.54 A	
	2025 season					
Chitosan 1%	0.00 r	0.14 k-n	0.21 ij	0.41 d	0.63 b	0.28 B
CMC 1%	0.00 r	0.12 l-o	0.18 jk	0.35 ef	0.55 c	0.24 C
Chitosan 1% + cysteine 1%	0.00 r	0.05 p-r	0.11 m-o	0.17 j-l	0.32 fg	0.13 F
CMC 1% + cysteine 1%	0.00 r	0.03 qr	0.07 o-q	0.14 k-n	0.27 gh	0.10 G
Chitosan 1% + ascorbic acid 5%	0.00 r	0.10 n-p	0.16 j-m	0.32 fg	0.45 d	0.21 D
CMC 1% + ascorbic acid 5%	0.00 r	0.07 o-q	0.13 k-n	0.25 hi	0.40 de	0.17 E
Control	0.00 r	0.21 ij	0.31 fg	0.63 b	0.92 a	0.41 A
Mean	0.00 E	0.10 D	0.17 C	0.32 B	0.51 A	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05. Carboxymethyl cellulose (CMC), Control (Spray with distilled water).

TABLE 2. Effect of some postharvest treatments and storage periods on general appearance (score) of lettuce heads during storage at 0°C in 2024 and 2025 seasons.

Treatments	2024 season					
	Storage periods (days)					
	0	**4**	**8**	**12**	**16**	**Mean**
Chitosan 1%	9.00 a	9.00 a	7.67 bc	6.33 de	5.00 f	**7.40 D**
CMC 1%	9.00 a	9.00 a	8.33 ab	7.00 cd	6.33 de	**7.93 C**
Chitosan 1% + cysteine 1%	9.00 a	9.00 a	9.00 a	9.00 a	8.33 ab	**8.87 A**
CMC 1% + cysteine 1%	9.00 a	9.00 a	9.00 a	9.00 a	8.33 ab	**8.87 A**
Chitosan 1% + ascorbic acid 5%	9.00 a	9.00 a	9.00 a	7.67 bc	7.00 cd	**8.33 BC**
CMC 1% + ascorbic acid 5%	9.00 a	9.00 a	9.00 a	8.33 ab	7.67 bc	**8.60 AB**
Control	9.00 a	7.67 bc	5.67 ef	3.67 g	2.33 h	**5.67 E**
Mean	**9.00 A**	**8.81 A**	**8.24 B**	**7.29 C**	**6.43 D**	
	2025 season					
Chitosan 1%	9.00 a	9.00 a	7.67 bc	6.33 de	5.00 f	**7.40 D**
CMC 1%	9.00 a	9.00 a	8.33 ab	7.00 cd	6.33 de	**7.93 C**
Chitosan 1% + cysteine 1%	9.00 a	9.00 a	9.00 a	9.00 a	8.33 ab	**8.87 A**
CMC 1% + cysteine 1%	9.00 a	9.00 a	9.00 a	9.00 a	8.33 ab	**8.87 A**
Chitosan 1% + ascorbic acid 5%	9.00 a	9.00 a	9.00 a	7.67 bc	7.00 cd	**8.33 BC**
CMC 1% + ascorbic acid 5%	9.00 a	9.00 a	9.00 a	8.33 ab	7.67 bc	**8.60 AB**
Control	9.00 a	7.67 bc	5.67 ef	3.67 g	3.00 g	**5.80 E**
Mean	**9.00 A**	**8.81 A**	**8.24 B**	**7.29 C**	**6.52 D**	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05. Carboxymethyl cellulose (CMC), Control (distilled water).

TABLE 3. Effect of some postharvest treatments and storage periods on discoloration (score) of lettuce heads during storage at 0°C in 2024 and 2025 seasons.

Treatments	2024 season					
	Storage periods (days)					
	0	**4**	**8**	**12**	**16**	Mean
Chitosan 1%	1.00 e	1.00 e	1.67 d	2.33 c	2.67 c	**1.73 B**
CMC 1%	1.00 e	1.00 e	1.33 de	1.67 d	2.33 c	**1.47 C**
Chitosan 1% + cysteine 1%	1.00 e	1.00 e	1.00 e	1.00 e	1.33 de	**1.07 D**
CMC 1% + cysteine 1%	1.00 e	1.00 e	1.00 e	1.00 e	1.33 de	**1.07 D**
Chitosan 1% + ascorbic acid 5%	1.00 e	1.00 e	1.00 e	1.33 de	1.67 d	**1.20 D**
CMC 1% + ascorbic acid 5%	1.00 e	1.00 e	1.00 e	1.00 e	1.33 de	**1.07 D**
Control	1.00 e	1.67 d	2.33 c	3.67 b	5.00 a	**2.73 A**
Mean	**1.00 D**	**1.10 D**	**1.33 C**	**1.71 B**	**2.24 A**	
	2025 season					
Chitosan 1%	1.00 g	1.00 g	1.67 ef	2.00 de	2.67 c	**1.67 B**
CMC 1%	1.00 g	1.00 g	1.33 fg	1.67 ef	2.33 cd	**1.47 B**
Chitosan 1% + cysteine 1%	1.00 g	1.00 g	1.00 g	1.00 g	1.33 fg	**1.07 C**
CMC 1% + cysteine 1%	1.00 g	1.00 g	1.00 g	1.00 g	1.33 fg	**1.07 C**
Chitosan 1% + ascorbic acid 5%	1.00 g	1.00 g	1.00 g	1.33 fg	1.67 ef	**1.20 C**
CMC 1% + ascorbic acid 5%	1.00 g	1.00 g	1.00 g	1.00 g	1.33 fg	**1.07 C**
Control	1.00 g	1.33 fg	2.00 de	3.67 b	5.00 a	**2.60 A**
Mean	**1.00 D**	**1.05 D**	**1.29 C**	**1.67 B**	**2.24 A**	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05. Carboxymethyl cellulose (CMC), Control (Spray with distilled water).

TABLE 4. Effect of some postharvest treatments and storage periods on color (L* value) of lettuce heads during storage at 0°C in 2024 and 2025 seasons.

Treatments	2024 season					
	Storage periods (days)					
	0	4	8	12	16	Mean
Chitosan 1%	59.52 a	58.54 a-c	55.73 hi	53.76 j	49.39 m	**55.39 E**
CMC 1%	59.52 a	58.66 a-c	56.18 gh	54.42 j	50.69 l	**55.89 D**
Chitosan 1% + cysteine 1%	59.52 a	59.15 a-c	58.71 a-c	58.18 c-e	55.92 gh	**58.30 A**
CMC 1% + cysteine 1%	59.52 a	59.27 ab	58.98 a-c	58.62 a-c	57.25 d-f	**58.73 A**
Chitosan 1% + ascorbic acid 5%	59.52 a	58.76 a-c	56.94 fg	55.59 hi	52.30 k	**56.62 C**
CMC 1% + ascorbic acid 5%	59.52 a	58.99 a-c	58.14 c-e	57.21 ef	54.23 j	**57.62 B**
Control	59.52 a	58.24 b-d	54.73 ij	50.82 l	45.19 n	**53.70 F**
Mean	**59.52 A**	**58.80 B**	**57.06 C**	**55.51 D**	**52.14 E**	
	2025 season					
Chitosan 1%	62.93 a	62.01 a-c	59.17 gh	57.17 j	52.79 m	**58.81 D**
CMC 1%	62.93 a	62.12 a-c	59.63 e-g	57.85 ij	54.10 l	**59.33 D**
Chitosan 1% + cysteine 1%	62.93 a	62.66 a-c	62.19 a-c	61.60 b-d	59.31 f-h	**61.74 A**
CMC 1% + cysteine 1%	62.93 a	62.78 ab	62.45 a-c	62.06 a-c	60.67 de	**62.18 A**
Chitosan 1% + ascorbic acid 5%	62.93 a	62.21 a-c	60.38 ef	59.01 g-i	55.71 k	**60.05 C**
CMC 1% + ascorbic acid 5%	62.93 a	62.45 a-c	61.58 cd	60.63 de	57.64 j	**61.05 B**
Control	62.93 a	61.69 b-d	58.17 h-j	54.24 l	48.60 n	**57.13 E**
Mean	62.93 A	62.27 B	60.51 C	58.94 D	55.55 E	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05. Carboxymethyl cellulose (CMC), Control (Spray with distilled water).

TABLE 5. Effect of some postharvest treatments and storage periods on color (hue angle h°) of lettuce heads during storage at 0°C in 2024 and 2025 seasons.

Treatments	2024 season					
	Storage periods (days)					
	0	4	8	12	16	Mean
Chitosan 1%	97.55 a	96.35 a-e	95.21 e-i	92.54 k	89.92 l	**94.32 C**
CMC 1%	97.55 a	96.62 a-d	95.46 d-h	92.63 jk	90.05 l	**94.46 C**
Chitosan 1% + cysteine 1%	97.55 a	97.17 ab	96.42 a-e	95.51 d-h	93.92 ij	**96.12 A**
CMC 1% + cysteine 1%	97.55 a	97.29 ab	96.88 a-c	96.19 b-f	94.97 f-i	**96.58 A**
Chitosan 1% + ascorbic acid 5%	97.55 a	96.59 a-d	95.61 c-g	94.18 hi	91.79 k	**95.15 B**
CMC 1% + ascorbic acid 5%	97.55 a	96.68 a-d	95.71 c-g	94.59 g-i	92.61 jk	**95.43 B**
Control	97.55 a	96.56 a-d	95.09 e-i	91.39 k	87.53 m	**93.62 D**
Mean	**97.55 A**	**96.75 B**	**95.77 C**	**93.86 D**	**91.54 E**	
	2025 season					
Chitosan 1%	99.30 a	98.35 a-e	97.02 g-j	94.31 l	91.67 n	**96.13 C**
CMC 1%	99.30 a	98.40 a-d	97.25 f-i	94.40 l	91.80 n	**96.23 C**
Chitosan 1% + cysteine 1%	99.30 a	98.96 a-c	98.20 b-f	97.27 e-i	95.67 k	**97.88 A**
CMC 1% + cysteine 1%	99.30 a	99.07 ab	98.65 a-c	97.95 c-g	96.72 h-k	**98.34 A**
Chitosan 1% + ascorbic acid 5%	99.30 a	98.43 a-d	97.40 d-i	95.95 jk	93.54 lm	**96.92 B**
CMC 1% + ascorbic acid 5%	99.30 a	98.48 a-d	97.49 d-h	96.35 i-k	94.36 l	**97.20 B**
Control	99.30 a	98.18 b-f	96.87 g-j	93.16 m	89.29 o	**95.36 D**
Mean	**99.30A**	**98.55 B**	**97.55 C**	**95.63 D**	**93.29 E**	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05. Carboxymethyl cellulose (CMC), Control (Spray with distilled water).

TABLE 6. Effect of some postharvest treatments and storage periods on firmness (kg/ cm^2) of lettuce heads during storage at 0°C in 2024 and 2025 seasons.

Treatments	2024 season					
	storage periods (days)					
	0	**4**	**8**	**12**	**16**	**Mean**
Chitosan 1%	3.12 a	2.87 a-f	2.59 b-g	2.36 g-i	2.02 ij	**2.59 B**
CMC 1%	3.12 a	2.88 a-e	2.60 b-g	2.38 f-i	2.03 h-j	**2.60 B**
Chitosan 1% + cysteine 1%	3.12 a	3.07 ab	2.92 a-e	2.69 a-g	2.62 a-g	**2.88 A**
CMC 1% + cysteine 1%	3.12 a	3.09 ab	3.04 a-d	2.76 a-g	2.65 a-g	**2.93 A**
Chitosan 1% + ascorbic acid 5%	3.12 a	3.04 a-d	2.87 a-f	2.61 b-g	2.54 d-g	**2.84 A**
CMC 1% + ascorbic acid 5%	3.12 a	3.06 a-c	2.89 a-e	2.67 a-g	2.55 d-g	**2.86 A**
Control	3.12 a	2.53 e-h	2.57 c-g	1.79 jk	1.31 k	**2.26 C**
Mean	**3.12 A**	**2.93 AB**	**2.78 B**	**2.46 C**	**2.25 D**	
	2025 season					
Chitosan 1%	3.57 a	3.34 a-d	3.07 e-g	2.82 h	2.46 i	**3.05 B**
CMC 1%	3.57 a	3.35 a-c	3.09 e-g	2.85 gh	2.48 i	**3.07 B**
Chitosan 1% + cysteine 1%	3.57 a	3.53 a	3.40 ab	3.15 c-e	3.07 e-g	**3.35 A**
CMC 1% + cysteine 1%	3.57 a	3.55 a	3.52 a	3.22 b-e	3.10 d-f	**3.39 A**
Chitosan 1% + ascorbic acid 5%	3.57 a	3.50 a	3.35 a-c	3.08 e-g	2.98 e-h	**3.30 A**
CMC 1% + ascorbic acid 5%	3.57 a	3.52 a	3.38 a-c	3.14 c-e	3.00 e-h	**3.32 A**
Control	3.57 a	3.05 e-h	2.88 f-h	2.15 j	1.66 k	**2.66 C**
Mean	**3.57 A**	**3.41 B**	**3.24 C**	**2.92 D**	**2.68 E**	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05. Carboxymethyl cellulose (CMC), Control (Spray with distilled water).

TABLE 7. Effect of some postharvest treatments and storage periods on ascorbic acid content (mg/100 g F.W.**) of lettuce heads during storage at 0°C in 2024 and 2025 seasons.**

Treatments	2024 season					
	storage periods (days)					
	0	**4**	**8**	**12**	**16**	**Mean**
Chitosan 1%	35.10 a	33.97 a-f	32.70 f-j	31.30 k-m	29.37 n	**32.49 C**
CMC 1%	35.10 a	34.00 a-e	32.77 e-j	31.50 j-m	29.52 n	**32.58 C**
Chitosan 1% + cysteine 1%	35.10 a	34.77 a-c	33.93 a-f	33.17 d-i	32.03 i-l	**33.80 AB**
CMC 1% + cysteine 1%	35.10 a	34.90 ab	34.40 a-d	33.83 a-f	33.20 d-i	**34.29 A**
Chitosan 1% + ascorbic acid 5%	35.10 a	34.63 a-c	33.53 c-h	32.37 h-k	30.87 lm	**33.30 B**
CMC 1% + ascorbic acid 5%	35.10 a	34.63 a-c	33.67 b-g	32.70 f-j	31.33 k-m	**33.49 B**
Control	35.10 a	33.90 a-f	32.40 g-k	30.47 mn	27.57 o	**31.89 D**
Mean	**35.10 A**	**34.40 B**	**33.34 C**	**32.19 D**	**30.55 E**	
	2025 season					
Chitosan 1%	36.70 a	35.60 b-e	34.30 f-h	32.93 j-l	30.97 n	**34.10 D**
CMC 1%	36.70 a	35.63 b-e	34.37 f-h	33.13 i-k	31.13 mn	**34.19 D**
Chitosan 1% + cysteine 1%	36.70 a	36.37 a-c	35.50 c-e	34.77 e-g	33.60 h-j	**35.39 B**
CMC 1% + cysteine 1%	36.70 a	36.50 ab	35.97 a-d	35.43 c-e	34.77 e-g	**35.87 A**
Chitosan 1% + ascorbic acid 5%	36.70 a	36.23 a-c	35.13 d-f	34.00 g-i	32.47 kl	**34.91 C**
CMC 1% + ascorbic acid 5%	36.70 a	36.27 a-c	35.23 d-f	34.30 f-h	32.90 j-l	**35.08 BC**
Control	36.70 a	35.53 b-e	34.00 g-i	32.10 lm	29.17 o	**33.50 E**
Mean	**36.70 A**	**36.02 B**	**34.93 C**	**33.81 D**	**32.14 E**	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05. Carboxymethyl cellulose (CMC), Control (Spray with distilled water).

TABLE 8. Effect of some postharvest treatments and storage periods on TSS (%) of lettuce heads during storage at 0°C in 2024 and 2025 seasons.

Treatments	2024 season					
	Storage periods (days)					
	0	4	8	12	16	Mean
Chitosan 1%	4.77 a	4.40 a-e	4.07 e-i	3.60 j-m	3.07 n	**3.98 D**
CMC 1%	4.77 a	4.43 a-e	4.13 d-i	3.73 i-l	3.23 mn	**4.06 CD**
Chitosan 1% + cysteine 1%	4.77 a	4.57 a-c	4.33 b-f	4.13 d-i	3.87 g-j	**4.33 AB**
CMC 1% + cysteine 1%	4.77 a	4.67 ab	4.50 a-d	4.30 b-f	4.07 e-i	**4.46 A**
Chitosan 1% + ascorbic acid 5%	4.77 a	4.50 a-d	4.17 c-h	3.80 h-k	3.40 k-n	**4.13 CD**
CMC 1% + ascorbic acid 5%	4.77 a	4.53 a-d	4.23 c-g	3.97 f-j	3.63 j-m	**4.23 BC**
Control	4.77 a	4.28 b-g	3.80 h-k	3.35 l-n	2.63 o	**3.77 E**
Mean	**4.77 A**	**4.48 B**	**4.18 C**	**3.84 D**	**3.41 E**	
	2025 season					
Chitosan 1%	5.23 a	4.90 a-f	4.53 d-k	4.10 k-m	3.43 n	**4.44 D**
CMC 1%	5.23 a	4.93 a-e	4.60 c-k	4.23 i-m	3.70 mn	**4.54 CD**
Chitosan 1% + cysteine 1%	5.23 a	5.10 a-c	4.83 a-g	4.67 b-j	4.37 f-l	**4.84 AB**
CMC 1% + cysteine 1%	5.23 a	5.17 ab	4.97 a-e	4.80 a-h	4.53 d-k	**4.94 A**
Chitosan 1% + ascorbic acid 5%	5.23 a	5.00 a-e	4.63 b-k	4.30 g-l	3.87 l-n	**4.61 B-D**
CMC 1% + ascorbic acid 5%	5.23 a	5.07 a-d	4.73 a-i	4.50 e-k	4.13 j-m	**4.73 A-C**
Control	5.23 a	4.77 a-i	4.27 h-l	3.83 l-n	3.10 o	**4.24 E**
Mean	**5.23 A**	**4.99 B**	**4.65 C**	**4.35 D**	**3.88 E**	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05. Carboxymethyl cellulose (CMC), Control (Spray with distilled water).

TABLE 9. Effect of some postharvest treatments and storage periods on total phenolic content (mg GEA /g F.W.) of lettuce heads during storage at 0°C in 2024 and 2025 seasons.

Treatments	2024 season					
	Storage periods (days)					
	0	4	8	12	16	Mean
Chitosan 1%	0.27 r	0.76 mn	1.22 gh	1.67 d	2.14 b	**1.21 B**
CMC 1%	0.27 r	0.70 n	1.05 j	1.44 e	1.89 c	**1.07 C**
Chitosan 1% + cysteine 1%	0.27 r	0.44 pq	0.73 n	0.96 k	1.32 f	**0.74 F**
CMC 1% + cysteine 1%	0.27 r	0.37 q	0.51 op	0.69 n	0.95 k	**0.56 G**
Chitosan 1% +ascorbic acid 5%	0.27 r	0.58 o	0.91 kl	1.27 fg	1.67 d	**0.94 D**
CMC 1% + ascorbic acid 5%	0.27 r	0.53 op	0.84 lm	1.09 ij	1.47 e	**0.84 E**
Control	0.27 r	1.14 hi	1.64 d	2.21 b	2.84 a	**1.62 A**
Mean	**0.27 E**	**0.65 D**	**0.98 C**	**1.33 B**	**1.76 A**	
	2025 season					
Chitosan 1%	0.21 r	0.69 lm	1.13 gh	1.57 e	2.03 c	**1.13 B**
CMC 1%	0.21 r	0.62 mn	0.95 i	1.33 f	1.76 d	**0.97 C**
Chitosan 1% + cysteine 1%	0.21 r	0.37 pq	0.63 mn	0.85 j	1.19 g	**0.65 F**
CMC 1% + cysteine 1%	0.21 r	0.30 q	0.42 op	0.59 n	0.83 jk	**0.47 G**
Chitosan 1% + ascorbic acid 5%	0.21 r	0.50 o	0.81 jk	1.17 g	1.55 e	**0.85 D**
CMC 1% + ascorbic acid 5%	0.21 r	0.45 op	0.75 kl	0.98 i	1.35 f	**0.75 E**
Control	0.21 r	1.08 h	1.56 e	2.12 b	2.74 a	**1.54 A**
Mean	**0.21 E**	**0.57 D**	**0.89 C**	**1.23 B**	**1.64 A**	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05. Carboxymethyl cellulose (CMC), Control (Spray with distilled water).

Table 10. Effect of some postharvest treatments and storage periods on phenylalanine ammonia-lyase (unit/g fresh weight) activity of lettuce heads during storage at 0°C in 2024 and 2025 seasons.

Treatments	2024 season					
	Storage periods (days)					
	0	4	8	12	16	Mean
Chitosan 1%	24.73 a	23.47 d-g	22.10 i-k	20.83 op	19.80 q	22.19 D
CMC 1%	24.73 a	23.63 c-f	22.43 h-j	21.33 l-o	20.03 q	22.43 D
Chitosan 1% + cysteine 1%	24.73 a	24.47 ab	23.83 b-e	22.37 h-j	21.73 j-m	23.43 B
CMC 1% + cysteine 1%	24.73 a	24.57 ab	24.27 a-c	23.87 b-e	23.00 f-h	24.09 A
Chitosan 1%+ascorbic acid5%	24.73 a	23.92 b-e	22.82 g-i	21.80 j-m	20.92 no	22.84 C
CMC 1% + ascorbic acid 5%	24.73 a	24.13 a-d	23.23 e-g	22.03 j-l	21.20 m-o	23.07 C
Control	24.73 a	23.03 f-h	21.60 k-n	20.10 pq	18.33 r	21.56 E
Mean	**24.73 A**	**23.89 B**	**22.90 C**	**21.76 D**	**20.72 E**	
	2025 season					
Chitosan 1%	26.57 a	25.33 b-g	24.00 h-l	22.70 m-o	21.63 o	**24.05 E**
CMC 1%	26.57 a	25.50 a-f	24.33 f-k	23.20 k-m	21.87 no	**24.29 DE**
Chitosan 1% + cysteine 1%	26.57 a	26.33 a-c	25.73 a-e	24.23 g-l	23.57 j-m	**25.29 B**
CMC 1% + cysteine 1%	26.57 a	26.43 ab	26.17 a-c	25.73 a-e	24.90 d-i	**25.96 A**
Chitosan 1% + ascorbic acid 5%	26.57 a	25.80 a-e	24.73 e-j	23.67 j-m	22.77 m-o	**24.71 CD**
CMC 1% + ascorbic acid 5%	26.57 a	26.00 a-d	25.13 c-h	23.90 i-m	23.03 l-n	**24.93 BC**
Control	26.57 a	24.90 d-i	23.43 k-m	21.97 no	20.17 p	23.41 F
Mean	**26.57 A**	**25.76 B**	**24.79 C**	**23.63 D**	**22.56 E**	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05. Carboxymethyl cellulose (CMC), Control (Spray with distilled water).

Table 11. Effect of some postharvest treatments and storage periods on Polyphenol oxidase (PPO) activity (unit/g fresh weight) of lettuce heads during storage at 0°C in 2024 and 2025 seasons.

Treatments	2024 season					
	Storage periods (days)					
	0	4	8	12	16	Mean
Chitosan 1%	38.73 q	40.93 n	43.30 hi	45.63 e	47.77 c	**43.27 B**
CMC 1%	38.73 q	40.53 no	42.43 jk	44.47 g	46.50 d	**42.53 C**
Chitosan 1% + cysteine 1%	38.73 q	39.77 p	40.87 n	42.30 kl	43.70 h	**41.07 F**
CMC 1% + cysteine 1%	38.73 q	39.17 q	40.33 o	41.57 m	42.83 ij	**40.53 G**
Chitosan 1% + ascorbic acid 5%	38.73 q	40.30 o	42.07 k-m	43.77 h	45.67 e	**42.11 D**
CMC 1% + ascorbic acid 5%	38.73 q	40.20 op	41.83 lm	43.40 h	45.03 f	**41.84 E**
Control	38.73 q	42.43 jk	46.10 de	49.97 b	54.07 a	**46.26 A**
Mean	**38.73 E**	**40.48 D**	**42.42 C**	**44.44 B**	**46.51 A**	
	2025 season					
Chitosan 1%	36.93 r	39.10 n-p	41.50 g-k	43.80 d-f	45.97 c	**41.46 B**
CMC 1%	36.93 r	38.70 op	40.63 i-m	42.63 fg	44.70 cd	**40.72 C**
Chitosan 1% + cysteine 1%	36.93 r	37.93 p-r	39.07 n-p	40.47 j-m	41.90 g-i	**39.26 E**
CMC 1% + cysteine 1%	36.93 r	37.33 qr	38.53 o-q	39.73 m-o	41.03 h-l	**38.71 E**
Chitosan 1% + ascorbic acid 5%	36.93 r	38.47 o-q	40.27 k-n	41.93 gh	43.87 d-f	**40.29 CD**
CMC 1% + ascorbic acid 5%	36.93 r	38.37 pq	40.03 l-n	41.57 g-j	43.23 ef	**40.03 D**
Control	36.93 r	40.60 j-m	44.30 de	48.13 b	52.27 a	**44.45 A**
Mean	**36.93 E**	**38.64 D**	**40.62 C**	**42.61 B**	**44.71 A**	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05. Carboxymethyl cellulose (CMC), Control (Spray with distilled water).

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تأثير بعض معاملات ما بعد الحصاد على الجودة و القدرة التخزينية لرؤوس الخس أثناء التخزين المبرد

شيرين عطا عطاالله ، نعمه محمد حسين و صفاء زكريا

قسم بحوث تداول الخضر معهد بحوث البساتين مركز البحوث الزراعية الجيزة مصر

الملخص

تم حصاد رؤوس الخس (صنف آيسبرج) في مرحلة النضج المناسبة للتسويق خلال موسمي ٢٠٢٤ و ٢٠٢٥ لدراسة تأثير بعض معاملات ما بعد الحصاد [الشيتوسان بتركيز ١% والكربوكسي ميثيل سليلوز بتركيز١ % منفردا و كل منهما مع السيستئين بتركيز١ % وحمض الأسكوربيك بتركيز ٥%] بجانب المعاملة الكنترول (الرش بالماء المقطر) في الحفاظ على الجودة و تحسين القدرة التخزينية لرؤوس الخس اثناء التخزين على صفر درجة مئوية ورطوبة نسبية ٩٥% لمدة ١٦ يوم.

أوضحت النتائج التي تم الحصول عليها أن جميع معاملات ما بعد الحصاد كانت الأكثر فاعلية في الحفاظ على صفات الجودة للرأس، و التحكم فى تغير لون الرؤوس، والمظهر العام لرؤوس الخس مقارنة بالمعاملة الكنترول ومع ذلك، كانت رؤوس الخس المعاملة بـ كربوكسي ميثيل سليلوز بتركيز ١% + السيستئين بتركيز ١% هي المعاملة الأكثر فاعلية في تقليل نسبة الفقد فى الوزن، والتغير فى اللون، و نشاط انزيم فنيل الانين امينوليز (PAL) ، ونشاط انزيم البولي فينول أكسيديز (PPO)، والحفاظ على صفات الجودة (الصلابة، والمحتوى من حمض الأسكوربيك ، ونسبة المواد الصلبة الذائبة الكلية، ومحتوى الفينولات الكلية) وأعطت مظهرًا ممتازًا للرؤوس بعد ١٦ يوم من التخزين على صفر درجة مئوية.

الكلمات الدالة: رؤوس الخس، كربوكسي ميثيل سليلوز، الشيتوسان، السيستئين، حمض الأسكوربيك، الجودة، التخزين المبرد.