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Research Article

Effect of sonication-assisted cinnamon extract on the physicochemical and quality parameters of fresh-cut carrots

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ABSTRACT

The market for minimally processed produce has seen significant growth due to modern lifestyles. However, fresh-cut fruits and vegetables face significant challenges related to quality loss and loss of textural properties. Bioactive coatings are a promising method to lessen these deteriorative effects. This research evaluated the effectiveness of antioxidant-enriched edible coating incorporating sonication-assisted cinnamon extract for preserving the quality of fresh-cut carrots during storage. Cinnamon's bioactive compounds were obtained via sonication-assisted aqueous extraction. The samples were stored at refrigerated temperature, and quality analyses were performed for a twenty-one-day period. Physicochemical tests included moisture loss percentage, titratable acidity, total soluble solids, texture, color properties, and vitamin C content. Analysis indicated that coated samples demonstrated better retention of quality parameters relative to control samples. Weight loss was slower for treated samples at 20.51% as compared to untreated samples at 19.02%. These findings indicate that antioxidant infused edible coatings could be a viable strategy for prolonging the shelf life of minimally processed food products.

Keywords: Sonication; cinnamon; fresh cut; carrot; edible coating; antioxidants.

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INTRODUCTION

In today's world, increasing income levels, fast-paced urban life and improved storage infrastructure have increased the demand for convenience foods which include fresh-cut fruits and vegetables. These products are processed and ready to eat or cook while maintaining the fresh qualities of the raw produce (Raffo and Paoletti, 2022). Fresh-cut vegetables spoil quickly due to browning, moisture loss, microbial contamination and loss of nutritional content caused by tissue injury during processing or physical damage during storage/transport (Rasane et al., 2024; Anand and Barua, 2022). Additionally, higher respiration rate, increased enzyme activity and subsequent microbial growth accelerate post-harvest loss in fresh produce (Jain et al., 2023). Recent researches have observed that advancements in preservation technologies including non-thermal and physical methods like coatings, are important in order to extend shelf life and to enhance the quality of fresh-cut fruits and vegetables (Chen et al., 2024).

Carrot (*Daucus carota* L.) is a root vegetable that is typically consumed in its raw state or through various culinary recipes. It contains essential minerals (calcium, iron, phosphorus, magnesium, sodium and other elements) and various phenolic antioxidants (Mandrich et al., 2023). The shelf life of minimally processed (fresh-cut) carrots is low due to physiological degradation. This decline is characterized by variations in surface color, loss of cellular structure, changes in taste and biochemical changes (Condurso et al., 2020). Research studies have discovered various preservation strategies to address these challenges for fresh cut products. Nikhanj and Kaur (2022) studied the effectiveness of sodium hypochlorite, citric acid, benzoic acid, acetic acid and potassium metabisulphite as pretreatment on fresh-cut carrots, cucumbers and tomatoes. The findings demonstrated that the experimental pretreatments successfully extended the storage life of the. These results are also similar to the work of Chen et al. (2023), who utilized hydrogen sulfide, citric acid and ascorbic acid to avoid surface whitening of fresh-cut carrots. Increasing public demand regarding the potential adverse effects of synthetic food additives has helped this shift in the market. Research studies have been focused towards the development of safe alternatives to preserve and enhance the quality of fresh fruits and vegetables and related products (Teshome et al., 2022).

Edible coating has been used as an effective approach to reduce the negative effects of food processing. These coatings are defined as "thin material layers applied to food surfaces that are edible and considered part of the complete food product" (Rajial and Varma, 2024). The role of these coatings/films is to make a selectively permeable film that control the exchange of gases like O2, CO2 and water vapors. By controlling gas diffusion such coatings induce a modified atmosphere. This effectively slows down metabolic activity and slows down the respiration rate. So, this regulation acts to preserve the quality and enhance the post-harvest life of minimally processed fruits and vegetables. (Blancas-Benitez et al., 2022). Moreover, these edible coatings/films may provide additional nutritional value, improve product quality etc. Edible coatings/films lower dehydration, change gas diffusion and inhibit oxidative damage. In this way storage life is prolonged. In a recent study, minimally processed carrots were subjected to ultrasonic treatment, thermal processing and ascorbic acid addition. The results showed that combining ultrasound treatment with mild-heat and ascorbic acid treatment, lowered reactive oxygen species and reduced microbial contamination in fresh-cut carrots during storage (Wang et al 2024). Researchers have observed that combining natural plant extracts with non-thermal preservation methods (e.g., edible coatings) significantly improves shelf life of fresh-cut produce (Ma et al., 2024). Use of such coating films has been studied as protective technique in several research studies (Cannata et al., 2025; Kaur and Nikhanj, 2025; Viacava et al., 2022; Kumar et al., 2021).

Cinnamon is a spice which is used to improve the organoleptic characteristics of various foods, beverages and culinary products. It is rich in antioxidants and antimicrobial components. Cinnamon extracts contain high concentrations of antioxidants that neutralize/scavenge free radicals. The most significant property of cinnamon extract is that it acts a natural preservative (Sarengaowa et al., 2022). A Research study indicated that bioactive compounds of cinnamon can enhance the stability of minimally processed fruits and vegetables. Cinnamon exhibits antimicrobial activity against microorganisms (Alghuthaymi et al., 2021). The antimicrobial and antioxidant properties of cinnamon extract can help extend shelf life and maintain the quality of fruits and vegetables.

Considering the facts discussed above, this research was designed to develop a simple and economical edible coating using cinnamon extract which can prolong the shelf-life of fresh-cut carrots.

MATERIALS AND METHODS

Experimental activities were conducted at the Post Harvest Research Centre, Ayub Agricultural Research Institute, Faisalabad. Mature and fresh carrots were collected directly from the field and transported to the laboratory. After initial cleaning, the samples were cut into standardized slices (5 ± 3 mm in width and 45 ± 7 mm in length). Cinnamon extract was prepared using sonicator. Briefly, 250 grams of cinnamon (powdered from) was mixed with 1 litre of distilled water and sonicated (45 KHz frequency) for 60 minutes with occasional stirring at 45oC. Sonication is essential to break down cell walls which allows bioactive compounds to be released in the aqueous medium. This reduced the need for high temperature during extraction. The mixture was filtered and the extract was stored in glass containers for further use. Sample pieces of fresh cut carrots were dipped in coating solutions for five minutes. The coating solutions contained different concentrations of cinnamon extract at 1%, 3%, and 6% for T1, T2 and T3 respectively. Pectin was added at 2 % concentration and glycerol was added at 1% concentration, which remained constant. Following dipping, carrot samples were to air dried at ambient temperature (time: 10 hrs). Afterwards the samples were packaged in sealed bags and maintained at 4 to 5 °C for a period of 21 days.

Titratable acidity analysis

Titratable acidity was determined using the method illustrated by Zulfiqar et al. (2025). Initially, 10 ml of extracted carrot juice was poured into 100 ml of distilled water. This solution was titrated against a 0.1 N sodium hydroxide (NaOH). 1% phenolphthalein solution was added indicator. The titration end point was light pink color that remained stable for 10 seconds.

Total soluble solids (TSS)

TTS of carrot juice extracted from samples were measured through a digital refractometer (HI 96801). The obtained results were documented in °Brix (Rashid et al., 2024).

Color analysis

Surface color of the carrots treatments was quantified by utilizing a digital CR-400 Chroma Meter (Konica Minolta, Inc.). The recorded colorimetric readings i.e. L* (represented lightness and darkbess), a* (denoted red-green axis) and b* (denoted the yellow-blue axis) (Shafiq et al., 2025).

Firmness analysis

Carrot samples' firmness was determined using a penetrometer with a 3mm plunger. Carrot piece from each treatment was placed on a solid-rigid surface. Downward pressure was applied until the plunger penetrated the carrot piece. The penetration resistance/force was recorded as firmness in Kg/cm^2 (Dam et al., 2020).

Vitamin C (ascorbic acid) content

The total content of ascorbic acid within the fresh-cut carrot treatments was determined via 2,6-dichlorophenol indophenol titration technique. The methodology is illustrated by Babu et al. (2025). The procedure starts with the extraction of ascorbic acid from the carrot juice using a 4% oxalic acid solution as stabilizing medium. Titration was done using redox dye until a faint pink endpoint was observed. The exact volume of the titrant consumed was noted. The concentration of ascorbic acid was recorded as mg per 100 g of the sample taken. Calculated via the following equation:

$$\text{Dye factor} = 0.05/\text{Titre}$$

$$\text{Vitamin C (mg/100g)} = (\text{dye factor} \times \text{titre} \times \text{volume of sample made}) / (\text{Weight of sample} \times \text{volume of extract taken}) \times 100$$

Weight loss analysis

Weight loss percentage in fresh-cut samples was observed using the protocol illustrated by Mirani et al. (2022). Sample weights were noted using a digital analytical balance at intervals of 7, 14, and 21 days. The baseline measurement recorded on day 0. The data were used as the percentage of weight reduction relative to the initial weight for each specific time interval.

Statistical analysis

Analytical calculations for all parameters were conducted in triplicate. The resulting data were reported as the mean value. Analysis was conducted using a factorial design with two-way ANOVA (Montgomery and Runger, 2019) in Statistix 8.1 software to observe significant differences among treatment groups.

RESULTS AND DISCUSSION

Titratable acidity (%)

Statistical analysis indicated that the mean acidity values for the fresh-cut carrot samples significantly different ($p<0.05$). Mean values given in Table (1). A consistent upward trend in acidity levels was observed across all experimental treatments throughout the duration of storage. Minimum acidity level was recorded on day 0 (0.69%), while the maximum acidity was found on day 21 in treatment T0 (1.56%). Contradictory, Rashid et al. (2020) observed gradual decrease in titratable acidity when stored. The results depicted 3% and 5% cinnamon oil with 1% chitosan coating on apple had positive effect in maintaining the titratable acidity. Similarly, another study of Yu et al. (2021), on mango coated with cinnamon oil and chitosan, showed a decreasing trend in titratable acidity. But on comparison between the control specimens and the coating samples it was observed there was significantly slow decrease in titratable acidity of the coating samples.

Total soluble solids

Table (2) presents the variations of TSS in fresh-cut carrots throughout the storage period. A decreasing trend in TSS was observed across all treatments, with the highest value of 7.34 recorded on day 0. The lowest value of 6.02 measured on day 21 in T0 (Control). These observations align with the data reported by Nasrin et al. (2022), who noted comparable fluctuations in total soluble solids in carrots treated with various coating materials over 14 days of storage. Similarly, Alharaty and Ramaswamy, (2020) documented changing TSS levels in fresh-cut cauliflower stored at refrigeration temperature in different packaging materials for 20 days. Calculating total soluble solids is essential for evaluating the sensory qualities of produce. It acts as an indicator of maturity. A similar study showed that there was increase in total solids of tomato when stored in ambient temperatures. But tomatoes coated with cinnamon oil showed less variation in total solids as compared to non-coated samples. (Venkatachalam et al., 2024).

Color analysis

Table 1. Titratable acidity of treated carrot samples during storage.

	Storage Days			
Treatments	0	7	14	21
T_0	0.69±0.02[a]	0.88±0.04[b]	1.15±0.08[c]	1.56±0.02[e]
T_1	0.70±0.01[a]	0.85±0.02[b]	1.06±0.06[c]	1.51±0.01[e]
T_2	0.72±0.02[a]	0.83±0.01[b]	1.02±0.04[c]	1.46±0.03[e]
T_3	0.74±0.01[a]	0.80±0.03[b]	0.98±0.02[d]	1.25±0.01[f]

To=0% Cinnamon extract, T1= 1% Cinnamon extract, T2= 3% Cinnamon Extract, T3= 6% Cinnamon Extract.

Table 2. TSS of treated carrot samples during storage.

	Storage Days			
Treatments	0	7	14	21
T_0	7.34±0.02[a]	6.83±0.07[b]	6.41±0.04[c]	6.02±0.05[d]
T_1	7.33±0.02[a]	6.90±0.06[b]	6.49±0.06[c]	6.11±0.06[d]
T_2	7.32±0.01[a]	6.98±0.03[b]	6.62±0.02[c]	6.20±0.04[d]
T_3	7.34±0.03[a]	7.02±0.08[b]	6.75±0.01[d]	6.38±0.02[f]

To=0% Cinnamon extract, T1= 1% Cinnamon extract, T2= 3% Cinnamon Extract, T3= 6% Cinnamon Extract.

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Table 3. Color (L*) of treated and stored carrot samples.

	Storage Days			
Treatments	0	7	14	21
T_0	33.84±1.29[f]	50.46±0.95[a]	48.81±2.95[ab]	42.02±1.91[cde]
T_1	35.11±1.47[f]	42.07±1.41[cde]	44.08±3.15[bcd]	42.01±4.23[cde]
T_2	34.25±1.76[f]	28.00±4.91[g]	39.90±3.08[cde]	41.70±4.68[cde]
T_3	32.63±1.55[f]	37.29±1.91[ef]	39.76±5.06[cdef]	44.69±6.1[bc]

T_o=0% Cinnamon extract, T_1= 1% Cinnamon extract, T_2= 3% Cinnamon Extract, T_3= 6% Cinnamon Extract.

Table 4. Color (a*) of treated and stored carrot samples.

	Storage Days			
Treatments	0	7	14	21
T_0	31.89±1.87[a]	18.79±3.88[f]	22.1±3.90[ef]	26.63±2.42[abcd]
T_1	32.13±2.05[a]	31.98±4.96[ab]	30.70±1.44[abc]	27.11±1.20[cde]
T_2	33.07±2.27[a]	25.02±1.52[def]	29.75±1.92[abcd]	28.71±2.63[abcd]
T_3	32.15±2.36[a]	27.51±3.12[abcde]	31.40±5.39[abc]	29.93±1.91[abcd]

To=0% Cinnamon extract, T1= 1% Cinnamon extract, T2= 3% Cinnamon Extract, T3= 6% Cinnamon Extract.

Table 5. Color (b*) of treated and stored carrot samples.

	Storage Days			
Treatments	0	7	14	21
T_0	21.05±1.14[bcde]	20.38±3.88[cde]	20.97±2.15[abcde]	23.01±3.35[abc]
T_1	20.27±2.15[bcde]	23.97±1.92[a]	23.55±1.61[abc]	21.26±0.90[abcde]
T_2	21.19±2.73[bcde]	19.03±1.11[e]	21.98±0.87[abcd]	22.71±0.72[abc]
T_3	20.78±1.96[bcde]	21.53±0.77[abcde]	23.99±1.07[ab]	23.22±3.2[abc]

To=0% Cinnamon extract, T1= 1% Cinnamon extract, T2= 3% Cinnamon Extract, T3= 6% Cinnamon Extract.

The color parameters; L*, a* and b* coordinates for the fresh-cut carrot samples, are illustrated in tables 3, 4, and 5. The data demonstrated an elevation in L* values across all experimental groups until day 7. A progressive reduction was observed with increase in storage. The a* and b* values exhibited no statistically significant variations between treatments during the entire period. The lowest L* value of 28.00 for T2 was recorded on day 7, while the highest L* value of 50.46 T0 was observed on day 14. For a* values, the maximum reading of 33.07 was observed on day 0, the minimum value of 25.02 was found on day 7. b* value; the highest measurement of 23.97 was recorded on day 7 in T1, the lowest value of 19.03 was noted on day 7 in T2. Changes in carrot color resulted from minimal processing techniques and storage time (Fai et al., 2016). The study conducted by Venkatachalam et al. (2024), indicated that the combined application of chitosan and cinnamon oil effectively maintained color in tomato relative to the untreated/uncoated control. Although variations were observed, a reduction in color parameters was observed across all experimental treatments. This degradation was more prominent in the control uncoated group compared to the treated sample groups.

Firmness

Table (6) presents the values of textural firmness of fresh-cut carrots throughout the storage interval. A gradual loss in firmness was seen in all treatment groups. The maximum peak of 1.76 was recorded at day 0 in T2. The minimum value of 1.15 was recorded at day 21 in the T0 control group. Loss of rigidity is linked to the enzymatic degradation of insoluble protopectin into soluble pectin and pectic acid (Dam et al., 2020). Research published by Naqash et al. (2022) demonstrated that fresh-cut apples treated with cinnamon oil significantly slowed down softening and the firmness was retained during storage period.

The softening of fresh produce is associated with the degradation of cell wall carbohydrates by hydrolytic enzymes. This biochemical activity facilitates the solubilization of pectin, leading to the disintegration of the primary cell wall. Research study by Hanani et al. (2023) demonstrated that the application of cinnamon oil enhanced the textural firmness of fresh-cut guavas. Cinnamon oil may have inhibited microbial proliferation and reduce respiration rates during storage.

Table 6. Firmness of treated and stored carrot samples.

	Storage Days			
Treatments	0	7	14	21
T_0	1.80±0.03[ab]	1.60±0.03[d]	1.32±0.03[f]	1.15±0.02[g]
T_1	1.77±0.02[a]	1.67±0.02[c]	1.47±0.04[e]	1.24±0.03[h]
T_2	1.76±0.03[a]	1.69±0.02[bc]	1.45±0.03[e]	1.26±0.03[h]
T_3	1.77±0.01[a]	1.67±0.04[cd]	1.44±0.04[e]	1.29±0.05[h]

To=0% Cinnamon extract, T1= 1% Cinnamon extract, T2= 3% Cinnamon Extract, T3= 6% Cinnamon Extract.

Table 7. Vitamin C content of treated and stored carrot samples.

	Storage Days			
Treatments	0	7	14	21
T_0	13.94±0.02[a]	11.98±0.11[e]	11.04±0.06[f]	7.74±0.21[i]
T_1	14.02±0.75[ab]	13.21±0.07[bcd]	11.29±0.11[g]	8.31±0.13[j]
T_2	14.11±0.11[abc]	13.47±0.45[cd]	11.34±0.14[g]	8.84±0.44[h]
T_3	14.09±0.15[abc]	13.69±0.17[d]	11.32±0.46[g]	8.95±0.07[h]

To=0% Cinnamon extract, T1= 1% Cinnamon extract, T2= 3% Cinnamon Extract, T3= 6% C.E.

Table 8. Weight loss percentage of treated and stored carrot samples.

	Storage Days			
Treatments	0	7	14	21
T_0	0.00±0.00[a]	24.57±0.06[b]	22.97±0.02[d]	19.02±0.05[f]
T_1	0.00±0.00[a]	23.03±0.04[c]	22.89±0.03[de]	20.73±0.03[g]
T_2	0.00±0.00[a]	23.01±0.03[c]	22.74±0.02[e]	20.66±0.08[g]
T_3	0.00±0.00[a]	22.98±0.08[c]	22.72±0.03[e]	20.51±0.09[g]

T_o=0% Cinnamon extract, T_1= 1% Cinnamon extract, T_2= 3% Cinnamon Extract, T_3= 6% Cinnamon Extract.

Vitamin C content

Table (7) presents the differences in the ascorbic acid concentration of fresh-cut carrots throughout the storage. The results indicate a gradual reduction in vitamin C levels across all groups. Maximum vitamin C content of 14.11 mg/100mL was noted in T0 on day 0. Minimum content of 7.74 mg/100mL was observed on day 21. Comparable results have been reported by Li et al. (2017) fresh-cut carrots stored at 4°C for 8 days. Lee and Kader, (2000) reported a decrease in vitamin C content in pitaya fruit (fresh cut) in 4 days of storage at 15°C. This decline may be due to ascorbate oxidase enzyme. This enzyme oxidizes ascorbic acid to dehydroascorbic acid under stress conditions. Increased polyphenoloxidase (PPO) activity promotes the translation of ascorbic acid to dehydroascorbic acid. Peeling and cutting operations expose cell contents, including polyphenoloxidase and their substrates. PPO catalyzes the oxidation of phenolic compounds to ortho-quinones. Ascorbic acid simultaneously converts to dehydroascorbic acid through a coupled reaction (Gonçalves et al., 2010). Use of cinnamon oil in an edible coating has been shown to affect the vitamin C contents in fresh-cut fruits and vegetables in various studies. A recent study reported the influence of a chitosan-based coating made using cinnamon oil on jujube fruits. Fruits were stored at 4°C for a 60-day duration. The application successfully deterred fungal decay. Reduction in ascorbic acid was observed over time. Chitosan-oil composite samples retained more vitamin C content (Xing et al., 2015). In another study, an edible coating containing cinnamon essential oil was used. It was reported these coatings preserved nutritional integrity by inhibiting microbial spoilage and ensuring the physiological stability and safety of the fresh produce throughout the storage period (Rashid et al., 2020). A study on strawberries showed that coating made with cinnamon oil helped to reduce loss of ascorbic acid stored at room temperature. Another study demonstrated that cinnamon oil incorporated coating reduced oxidation and preserved quality attributes including vitamin C content (Piechowiak and Skóra, 2023). In a study involving highbush blueberry fruit, cinnamon oil incorporated in a starch-gelatine mixed coating was found to positively influence the value of produce by inhibiting yeast and mold, though the impact on vitamin C specifically was not mentioned, the antioxidant activity was preserved during storage (Piechowiak et al., 2022).

Weight loss (%)

Table (8) illustrates the percentage of mass reduction in fresh-cut carrots over a 21-day storage duration. The analytical data reveal a linear progression in weight loss across all experimental groups throughout the observation period. The highest loss of 24.57% was recorded in T0 on day 7, while the lowest weight loss of 19.02% was noted in T0 on day 21. Weight loss represents an indicator of transpiration-driven dehydration in vegetables and involves moisture transfer from plant cells to the surrounding environment (Rehman et al., 2020). Therefore, it can be utilized to evaluate the efficacy of coating treatments in preserving fresh-cut carrots. Hanani et al. (2023) reported the changes in loss percentage of cut guava was delayed by the chitosan application and cinnamon extract as edible coating. . .

Results of Sarengaowa et al. (2022) indicated that the concentration of cinnamon oil significantly influenced the rate of mass reduction. Fresh-cut potatoes treated with a lower concentration of cinnamon oil within the chitosan-based edible coating demonstrated superior moisture retention compared to those treated with a 0.6% concentration. Specifically, weight loss in the 0.6% cinnamon oil group accelerated sharply after four days of storage. The application of cinnamon oil on pomegranate helped in reduction of weight. The results illustrated effectiveness of the coating material as a barrier. The presence of cinnamon oil acts as barrier by inhibiting water loss (Singla et al., 2022).

Carrot samples were treated with cinnamon extract. The samples were tested at intervals of 0, 7, 14, and 21 days. Treatments with higher concentration of cinnamon extract had enhanced preservation. Similar increase in acidity have been reported by previous studies, including fresh-cut onions (Piscopo et al., 2019) and minimally processed carrots (Talasila et al., 2012). The increase in acidity during storage may result from the oxidation of reducing sugars and the degradation of polysaccharides and pectic substances (Rashidi et al., 2009).

The total soluble solids (TSS) exhibited better stability in carrots treated with higher conc. of cinnamon extract. This implies that the extract plays its role in preservation. The decrease in TSS is primarily caused by loss/breakdown of soluble solids. This change is associated with respiration process and ripening process that degrades carbohydrates into other substances. Biochemical deterioration of starches is done by enzymes such as amylases, starch phosphorylase and 1,6-glucosidase. These compounds modulate hydrolysis of complex polysaccharides into saccharides like sucrose, glucose and fructose. These simple sugars are utilized as substrates in the primary metabolic processes of the cells (Gonçalves et al., 2010).

The weight loss data exhibited that carrots treated with higher concentrations of cinnamon extract, showed both antimicrobial properties and moisture retention properties. These results are similar to the findings of Kowalczyk et al. (2020), who reported increase in weight loss percentages in various carrot samples treated with various chemical agents during 12 days of storage. Structural firmness was better in the coated samples i.e. in those containing higher concentrations of cinnamon extract. Similar reduction in the firmness values of fresh-cut carrots were reported by Amanatidou et al. (2000), during refrigerated storage in perforated polyethylene packaging. Wang et al. (2015), reported a similar loss in the textural firmness of fresh-cut carrots treated with carrot puree-based edible films during 12 days of storage.

Statistical analysis exhibited no significant changes in a* and b*, a significant change in L* values was observed in the fresh-cut carrots treated with edible coatings. In a research study, Nasrin et al. (2012), reported an increase in the L* index of fresh-cut carrots stored at 5°C for 10 days. This phenomenon is also referred to as "white blush". It is frequently associated with surface dehydration and the lignification of wounded tissues in processed carrots.

Vitamin C content was effectively retained in sample groups treated with higher cinnamon extracts. This demonstrated that the antioxidant properties of cinnamon extract are effective. The findings have demonstrated that higher concentrations of cinnamon extract may preserve the quality characters of stored freshly cut carrots.

CONCLUSION

This study evaluated the effectiveness of edible coatings infused with sonication-assisted cinnamon extract for extending the life of fresh cut carrots. Findings exhibited the potential of such coatings/film to lower quality degradation during 21 days of storage. Fresh-cut carrots treated with pectin-based coatings containing cinnamon extract showed reduced weight loss, improved firmness retention and better color stability as compared to the uncoated control group samples. The results showed that this edible coating had multifunctional properties. It acted as protective barrier which reduced moisture loss and maintained structural firmness. The infusion of cinnamon extract acted as a potent natural antioxidant agent. This extract scavenged of reactive oxygen species that accumulate due to wound stress in fresh-cut tissues in fruits and vegetables. The extract helped in inhibition of lipid peroxidation of cell membranes by neutralizing these free radicals. Thus, extending the shelf life of these minimally processed carrots. The sonication-assisted cinnamon extract treatment offers a practical approach that can be integrated into existing fresh-cut processing lines with minimal modification. Its capability to improve shelf life and uphold market value makes it a promising natural preservation agent for industrial fresh-cut operations. Results have similarity with earlier researches, emphasizing potential of antioxidant-enriched coatings/films for prolonging the life of fresh-cut fruits and vegetables.

AUTHOR’S CONTRIBUTION

HN formal analysis, experimental work and writing original draft; HUN Conceptualization and data analysis; MHR Writing original draft preparation and formal analysis; SR Data curation, and review and editing; RZ Resource supervision and review and editing; BS Validation and data curation; MA data curation and supervised the project; SM Formatting and proof reading; SP Conceptualization, Formatting, Proof Reading; IB Proof reading and writing-reviewing, editing.

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AVAILABILITY OF DATA AND MATERIAL

Not applicable.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Not applicable.

CONSENT FOR PUBLICATION

This study does not include any personal data from any individuals in any capacity. All authors have consented to its publication.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

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