Research Paper

Future of Food: Journal on Food, Agriculture and Society
11 (3) July 2023

Effect of Different Treatments on Storage Quality of Celery Petioles

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Data of the article

First received : 1 November 2022 | Last revision received : 28 June 2023
Accepted : 18 July 2023| Published online :31 July 2023
DOI : 10.17170/kobra-202210056946

Keywords

Celery; Mixed Gases; Browning; Fresh-cut; Heat Treatment; MAP; Chitosan; Colour of petioles.

This study was conducted for two seasons 2021 and 2022 to evaluate the influence of the hot water at 45° C and 50° C, chitosan at 0.5%, and active modified atmosphere packaging (MAP) at 5% O_2 + 5% CO_2, 5% O_2 + 10% CO_2 and passive MAP presented as the control on quality attributes and browning of fresh-cut celery petioles during storage at 0° C for 16 days. The results indicated that all treatments were effective in reduced weight loss, colour changes, discolouration, chlorophyll loss, total microbial count, polyphenol oxidase activity and maintained total phenolic content and total chlorophyll and overall appearance of fresh-cut celery petioles as compared with passive MAP (control). Fresh-cut celery petioles treated with hot water at 45° C and 50° C and active MAP at 5% O_2 + 5% CO_2 were the most effective treatments in maintaining quality during all storage periods. However, samples treated with hot water at 45° C showed the best quality avoided the loss of green colour, retarded the growth of microorganisms, not exacted any browning in the cut surface of petioles and did not exhibit any changes in general appearance till the end of storage period (16 days of storage at 0° C), while hot water at 50 ° C and active MAP at 5% O_2 + 5% CO_2 rated good appearance at the same period.

1. Introduction

Fresh-cut of celery petioles provide a lot of benefits such as reduced risk of cancer and cardiovascular disease (Heim et al., 2003) and benefits for consumers and producers. Petioles are cut immediately after harvest and they are used as snacks on the run. Petioles of celery are highly perishable to decay, loss of green colour and to development of pithiness which is transformed into the parenchyma. The general appearance of pithiness is whitish regions and air space within the tissue, so, the quality and shelf life of celery are decreased (Saltveit and Mangrich 1996 and Viña and Chaves 2006).

One of the most problems affecting celery is postharvest browning at cut surfaces; this is a physiological disorder. The phenomenon basically appears on cut or damaged surfaces manifesting itself with black/brown pigments. Browning of the product loses its freshness and tends to be considered as a decayed or diseased product. This results in considerable economic losses as sales decrease because the product does not meet supermarket specifications. Cutting also results in nutrient leakage from cells and increased water vapour and gas permeability (Gómez and Artés 2005).
Some physical methods such as hot water treatment

(Loaiza-Velarde et al., 2003 and Bablar et al., 2022), Modified Atmosphere Packaging (Gómez and Artés 2005) and edible coating treatments (Raymond et al., 2012) have been applied as postharvest treatment to preserve the quality and prevent the browning of celery petioles during cold storage.

Chitosan coating is a flexible transparent and can function as a barrier to water vapour, gases, and other solutes and also as a carrier of many functional ingredients, such as antimicrobial and antioxidant agents, thus enhancing the quality and extending the shelf life of fresh and minimally processed fruits and vegetables (Shiekh et al., 2013). Chitosan has been applied successfully as a coating on food surfaces to extend shelf life effectively without compromising the natural taste of the product (Kumar et al., 2020). Also, chitosan contends a beneficial effect on reducing decay, weight loss, colour changes, loss of firmness, delayed softening of fruits (Raymond et al., 2012).

There are a lot of new solutions to slow down the physiological processes, and disorders and minimize microbial growth in fresh-cut celery petioles such as modified atmosphere and hot water treatments. This has been shown to have good control in the metabolism of tissues and maintaining the quality of products (Loaiza-Velarde et al., 2003, Xing et al., 2011, Xing et al., 2019 and Babalar et al., 2022). Additionally, hot water treatment reduced the phenylalanine ammonia-lyase activity (PAL), the accumulation of phenolic compounds, and inhibits the browning, Abdalla 2013, Kobayashi et al., 2021 and Babalar et al., 2022). Modified atmosphere packaging (MAP) is an atmosphere created around produce that is different from that of air, which brings beneficial effects like an extension of the shelf life of fresh produce. MAP can be passively created by the commodity itself through the respiration process wherein oxygen is consumed and carbon dioxide is evolved or actively by flushing in gases of known composition (Kader 2002 and Kobayashi et al., 2021). Depleted O_2 and/or enriched CO_2 levels of the tissue, so, the hot water treatment maintains the quality and inhibits the browning reaction and extends the shelf life of the product) Loaiza-Velarde et al., 2003) can reduce respiration, delay ripening, decrease ethylene production, retard textural softening, slow down compositional changes associated with ripening (Gómez and Artés 2005), thereby resulting in an extension in a shelf life (Kobayashi et al., 2021).

Cantwell and Suslow (2002) and Gómez and Artés (2005) recommended using the MAP of celery petioles which should be designed to maintain both O_2 and CO_2 as close as possible to these levels (2 to 5 kPa O_2 and 5 to 10 kPa CO_2 atmospheres at 2–4°C).

Minimally processed celery petioles stored at MAP treatments can improve the quality attributes, avoided loss of fresh green colour, and decreased the development of pithiness and minimize microbial growth, no off-odours and off-flavours (Gómez and Artés 2005 and Kobayashi et al., 2021). The present study investigated the effect of hot water, MAP and chitosan coating as a postharvest treatment on quality attributes and browning control of fresh-cut celery petioles during storage.

2. Materials and methods

2.1. Plant Material

A white variety of celery plants (Apium graveolens L.) cv, Royal Crown was grown in greenhouse conditions at the farm of Cairo University, Giza Governorate during two successive seasons 2021 and 2022. Once the plants reached commercial size (after about 2 months of being transplanted), they were harvested 4th and 6th December in the first and the second season, respectively, and brought to the laboratory and immediately cut. Leaves and basal segments of the rosettes were eliminated to obtain straightened petioles. They were washed in running drinking water to remove any soil residues, and subsequently cut with a sharpened knife in 20-cm long petioles. Chitosan solution (0.5%) was prepared by dissolving 5 grams in one litre of distilled water.

Immediately after cutting they were immersed in chlorinated water (100 ppm active chlorine) for 3 min. Four treatments were applied as the following; celery petioles dipped in distilled water (control), chitosan solution at 0.5%, hot water at 45° and 50° C for one min. to all treatments (ambient temperature is 20 to 25° C). All the previous treatments were air-dried and packed in trays sealed with polypropylene bags 30 mμ. thickness. As for the two treatments, it flushed with different gases at 5% O_2 + 5% CO_2 and 5% O_2 + 10% CO_2.

Each bag for all treatments contains 100 grams as an

ISSN-Internet 2197-411x OLCL 862804632

experimental unit and is stored at 0ºC (±1º C) and 95% relative humidity (RH). Randomly taken the three replicate samples. The following characteristics were examined at intervals (0, 4, 8, 12 and16) days:-
Weight Loss Percentage (%): the percentage of weight loss was assayed according to the description of Zhan et al., (2013).

General Appearance (GA): GA was evaluated using a scale from (1-9) with 9= excellent, 7= good, 5= fair, 3= poor, 1= unsalable and fruits rating (5) or below were considered unmarketable (the panel tests for general appearance, decay and chilling injury, evaluated by seven researchers at the postharvest vegetable lab.).
Colour: The colour was measured by using a camera Minolta CR-400 Chroma Meter (Minolta Co. ltd. Osaka, Japan) on two sides of cut petioles (outer and inner). Skin colour was measured and gloss was expressed in chromaticity values such as lightness (L) and b values, respectively. Three readings were taken at different locations of each fruit (Xing et al., 2011 and Xing et al., 2019).

Discolouration: Discolouration was evaluated on a scale of 1 to 5 where 1 = none, 2 = slight, 3 =moderate, 4 = severe and 5 = extra severe.

Chlorophyll Content Assay: according to the description Zhan et al., (2013) chlorophyll content was analysed with slight modification. According to the formulas of Lichtenthaler and Wellburn (1983), the chlorophyll a and chlorophyll b contents were calculated.

Microbiological Analysis: Total plate count was determined using plate count agar media. Plates were incubated at 35 ºC for 48±2 h (Andrews, 1992).

Enzyme Assay PPO Activity: PPO activity was determined by the method of (Saleh et al., 2013) with the following modification. The results were expressed as a percentage of the activity of the respective zero experiments.

Determination of Phenolic Compounds: The total phenols were quantified with the Folin–Ciocalteu reagent (Singleton et al., 1999). Absorbance readings were carried out at 760 nm in a spectrophotometer (Shimadzu U V-2401 PC, Kyo to, Japan).

Statistical Analysis: For each parameter at each storage time, the measurement was carried out three times. The collected data were submitted for analysis of variance using SPSS (version 11.0). One-way ANOVA was applied to compare the effect of treatments on measured parameters during storage using the least significant difference (LSD) test at 0.05 confidence level.

3.Results

3.1. Weight Loss Percentage

Data in Table (1) showed that the weight loss percentage of celery petioles increased consistently with the prolongation of storage periods.

All postharvest treatments reduced the loss of weight during storage. Moreover, the most effective treatments in reducing the weight loss% with no significant differences between them were MAP at 5% O_2 + 5% CO_2, hot water at 45°C or 50°C followed by MAP at 5% O_2 + 10 % CO_2, and chitosan at 0.5 % treatments with no significant differences between them. The control sample gave the highest values of weight loss.

The interaction between storage periods and postharvest treatments was significant; after 16 days of storage, the lowest value of weight loss was recorded in celery petioles treated with MAP at 5% O_2 + 5% CO_2, 0.17 and 0.15 percent in the first and second seasons, respectively. While, the highest ones were obtained from the control. 1.21 and 1.10 present in the first and second seasons respectively.

3.2. General appearance (GA)

Data in Table (2) show that there was a significant reduction in the general appearance (score) of celery petioles during cold storage periods.

Celery petioles treated with all treatments had significantly higher scores of appearance as compared with the control which recorded a lower score of GA and deteriorated rapidly. However, celery petioles treated with hot water at 45°C or 50°C and MAP at 5% O_2 + 5% CO_2 were the most effective for maintaining GA with no significant differences between them followed by MAP at 5% O_2 + 10 % CO_2 and chitosan at 0.5 % treatments with no significant differences between them, while control recorded the lowest ones.

In widespread, the interplay between postharvest treatments and storage periods was significant. Outcomes recorded that celery petioles dipping in hot water at 45°C treatment gave an excellent appearance and did not exhibit any changes in this appearance until the end of the storage period (16 days of storage at 0°C) (score 8.33 in both seasons), but celery petioles dipping in hot water at 50°C and MAP at 5% O_2 + 5% CO_2 rated good appearance (score 7.0) in both seasons at the same period. While MAP at 5% O_2 + 10% CO_2 treatment gave a good appearance (score 7.67) in both seasons after 12 days from storage. On the other hand, the control had an unsalable appearance (score 1.67 in both seasons) after 16 days of storage at 0°C.

3.3. Colour (L value)

adjustments in lightness (L value) were found at the end of storage as compared to the initial value. The lightness of fresh-cut celery petioles changed into suffering from storage time. A decrement in L value become detected by using prolonging the storage pe-

Table 1: Effect of some postharvest treatments on weight loss (%) of fresh-cut celery during storage at 0°C in 2021 and 2022 seasons.

	After 4 days	After 8 days	After 12 days	After 16 days	Mean
			2021		
45° C	0.03 F	0.07 EF	0.17 D-F	0.21 D-F	0.12 C
50° C	0.01 F	0.13 EF	0.18 D-F	0.20 D-F	0.13 C
CO2 5% + O_2 5%	0.03 F	0.10 EF	0.12 EF	0.17 D-F	0.11 C
CO2 10%+ O_2 5%	0.00 F	0.20 D-F	0.30 D-F	0.40 C-E	0.23 B
Chitosan	0.16 D-F	0.21 D-F	0.40 C-E	0.50 CD	0.32 B
Control	0.20 D-F	0.70 BC	1.02 AB	1.21 A	0.78 A
mean	0.07 C	0.23 B	0.37 AB	0.45 A	
			2022		
45° C	0.11 F-J	0.06 IJ	0.13 F-J	0.18 E-J	0.12 D
50° C	0.04 IJ	0.11 F-J	0.22 C-J	0.25 C-I	0.15 CD
CO2 5% + O_2 5%	0.02 J	0.09 G-IJ	0.11 F-J	0.15 F-J	0.09 D
CO2 10%+ O_2 5%	0.07 H-J	0.19 D-J	0.30 C-G	0.42 C	0.25 BC
Chitosan	0.13 F-J	0.28 C-H	0.32 C-F	0.38 C-E	0.28 B
Control	0.13 F-J	0.40 CD	0.87 B	1.10 A	0.63 A
mean	0.08 D	0.19 C	0.32 B	0.41 A	

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ISSN-Internet 2197-411x OLCL 862804632

Table 2: Effect of some postharvest treatments on general appearance (score) of celery during storage at 0°C in 2021 and 2022 seasons.

2021						
	After 0 day	**After 4 days**	**after 8 days**	**after 12 days**	**after 16 days**	**mean**
45°C	9.00 A	9.00 A	9.00 A	8.33 AB	8.33 AB	**8.73 A**
50°C	9.00 A	9.00 A	9.00 A	7.67 A-C	7.00 B-D	**8.33 A**
CO_2 5% + O_2 5%	9.00 A	9.00 A	9.00 A	7.67 A-C	7.00 B-D	**8.33 A**
CO_2 10%+ O_2 5%	9.00 A	8.33 AB	7.67 A-C	6.33 CD	5.67 D	**7.40 B**
Chitosan	9.00 A	7.00 BCD	6.33 CD	7.00 B-D	6.33 CD	**7.13 B**
Control	9.00 A	7.00 BCD	5.67 D	3.67 E	1.67 F	**5.40 C**
mean	**9.00 A**	**8.22 B**	**7.78 B**	**6.78 C**	**6.00 D**	
2022						
45° C	9.00 A	9.00 A	9.00 A	8.33 AB	8.33 AB	**8.73 A**
50° C	9.00 A	9.00 A	9.00 A	7.67 A-C	7.00 B-D	**8.33 A**
CO_2 5% + O_2 5%	9.00 A	9.00 A	9.00 A	7.67 A-C	7.00 B-D	**8.33 A**
CO_2 10%+ O_2 5%	9.00 A	8.33 AB	7.67 A-C	6.33 CD	5.67 D	**7.40 B**
Chitosan	9.00 A	7.00 B-D	7.00 B-D	7.00 B-D	6.33 CD	**7.27 B**
Control	9.00 A	7.00 B-D	6.33 CD	3.67 E	1.67 F	**5.53 C**
mean	**9.00 A**	**8.22 B**	**8.00 B**	**6.78 C**	**6.00 D**	

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riods (Table 3), resulting in a darker colour. However, all applied treatments show significantly higher L values compared with the control. Furthermore, fresh-cut celery petioles dipped in hot water at 45°C and MAP at 5% O_2 + 5% CO_2 61.02 and 55.45 (average in the two seasons respectively) being the most effective treatments in maintaining the L values, resulted in lighter colour followed by hot water, 50° C and chitosan with significant differences between them during storage, while control gives the lowest one of L values during storage, resulted in a darker colour.

3.4. Discolouration

Data in Table (4) indicated that there was an increment in discolouration (score) for the cut surface of celery petioles during cold storage.

All the used treatments reduced the incidence of discolouration compared to the control. Fresh-cut celery treated with hot water at 45° or 50° C and MAP at 5%O_2 + 5% CO_2 were the most effective treatments in this concern followed by chitosan treatment. MAP at 5%O_2 + 10% CO_2 was less effective in reducing the incidence of discolouration.

The interaction between treatments and storage periods was significant after 16 days of storage. Celery petioles treatment with hot water at 45° and MAP at 5%O_2 + 5% CO_2 did not show any changes in their colour till the end of storage periods (16 days). The sample treated with hot water at 50° C showed none to a slight score of 1.67 in both seasons, and chitosan

Table 3: Effect of some postharvest treatments on color (L. value) of fresh-cut celery during storage at 0°C in 2021 and 2022 seasons.

2021						
	After 0 day	**After 4 days**	**after 8 days**	**after 12 days**	**after 16 days**	**mean**
45° C	68.11 A	67.22 A	64.15 BC	61.22 D	60.00 D	**64.14 A**
50° C	68.11 A	64.62 BC	58.22 E	55.32 GH	53.10 IJ	**59.87 C**
CO_2 5% + O_2 5%	68.11 A	65.24 B	61.31 D	57.48 EF	54.62 HI	**61.35 B**
CO_2 10%+ O_2 5%	68.11 A	61.48 D	53.23 IJ	52.22 JK	48.30 L	**56.67 E**
Chitosan	68.11 A	63.41 C	56.40 FG	54.25 HI	50.70 K	**58.57 D**
Control	68.11 A	47.30 L	42.11 M	39.16 N	31.42 O	**45.62 F**
mean	**68.11 A**	**61.54 B**	**55.90 C**	**53.28 D**	**49.69 E**	
2022						
45° C	69.80 A	68.33 B	65.53 DE	62.73 F	62.04 F	**65.69 A**
50° C	69.80 A	67.23 BC	60.40 G	56.59 I	54.86 JK	**61.78 C**
CO_2 5% + O_2 5%	69.80 A	66.90 CD	62.27 F	58.54 H	56.28 I	**62.76 B**
CO_2 10%+ O_2 5%	69.80 A	62.60 F	54.40 K	53.88 K	50.23 M	**58.18 E**
Chitosan	69.80 A	65.00 E	57.00 I	56.10 IJ	52.34 L	**60.05 D**
Control	69.80 A	48.07 N	43.23 O	41.13 P	33.09 Q	**47.06 F**
mean	**69.80 A**	**63.02 B**	**57.14 C**	**54.83 D**	**51.47 E**	

Means in the same column having the same letter are not significantly different at 0.05 level by Duncan"s multiple rang test

treatment gave a slight score of 2.0 in both seasons. However, the control treatment resulted in severe discolouration with a high score of 4.33 in both seasons, in the same period.

3.5. Total chlorophyll content

Data in Table (5) revealed that there was in significant reduction in the total chlorophyll content of fresh-cut celery petioles during storage. All treatments significantly reduced the loss of total chlorophyll content as compared to control during cold storage. Fresh-cut celery petioles dipped in hot water at 45°C turned into the handiest treatment for lowering the loss of total chlorophyll content during storage followed by MAP at 5% O_2 + 5% CO_2 and hot water at 50°C treatments without a big difference among them, at the same time as the other treatments had been much less potent on this challenge. The lowest value of total chlorophyll content was obtained from the control. In preferred, the interaction between treatments and storage periods turned significant. After 16 days of storage at 0°C, data revealed that fresh-cut celery petioles dipped in hot water at 45°C or 50°C and MAP at 5% O_2 + 5% CO_2 turned into the handiest treatment for lowering the loss of the total chlorophyll content 28.0, 26.0, and 26.13 mg/100g FW (average in the two seasons respectively) with no significant differences between them compared with the other treatments, while control had the lowest value of total chlorophyll content 13.34 mg/100g FW (average in the seasons).

3.6. Total microbial count

ISSN-Internet 2197-411x OLCL 862804632

Table 4: Effect of some postharvest treatments on discoloration (score) of fresh-cut celery during storage at 0°C in 2021 and 2022 seasons.

2021						
	After 0 day	**After 4 days**	**after 8 days**	**after 12 days**	**after 16 days**	**mean**
45° C	1.00 G	1.00 G	1.00 G	1.00 G	1.00 G	**1.00 C**
50° C	1.00 G	1.00 G	1.00 G	1.00 G	1.67 EF	**1.13 C**
CO_2 5% + O_2 5%	1.00 G	1.00 G	1.00 G	1.00 G	1.00 G	**1.00 C**
CO_2 10%+ O_2 5%	1.00 G	1.00 G	1.67 EF	2.33 CD	2.67 C	**1.73 B**
Chitosan	1.00 G	1.00 G	1.00 G	1.00 G	2.00 DE	**1.20 C**
Control	1.00 G	1.33 FG	2.00 DE	3.33 B	4.33 A	**2.40 A**
mean	**1.00 D**	**1.06 CD**	**1.28 C**	**1.61 B**	**2.11 A**	
2022						
45° C	1.00 D	1.00 D	1.00 D	1.00 D	1.00 D	**1.00 C**
50° C	1.00 D	1.00 D	1.00 D	1.00 D	1.67 CD	**1.13 C**
CO_2 5% + O_2 5%	1.00 D	1.00 D	1.00 D	1.00 D	1.00 D	**1.00 C**
CO_2 10%+ O_2 5%	1.00 D	1.00 D	1.33 CD	2.00 BC	2.67 B	**1.60 B**
Chitosan	1.00 D	1.00 D	1.00 D	1.00 D	2.00 BC	**1.20 C**
Control	1.00 D	1.00 D	1.33 CD	2.67 B	4.33 A	**2.07 A**
mean	**1.00 C**	**1.00 C**	**1.11 C**	**1.44 B**	**2.11 A**	

Means in the same column having the same letter are not significantly different at 0.05 level by Duncan"s multiple rang test

Data in Table (6) indicate that microbial growth in celery petioles increased significantly with increasing the storage period particularly in the untreated control.

All used treatments had lower levels of microbial load in comparison to the control treatment. Fresh-cut celery petioles treated with hot water at 45°C were the most effective in reducing microbial growth followed by hot water at 50°C and MAP at 5% O_2 + 5% CO_2 treatments with no significant differences between them, while the other treatments showed less effective in reducing microbial growth. Control had higher levels of the total microbial count.

In preferred, the interaction between treatments and storage periods turned into significant data revealed that after 16 days of storage fresh-cut celery petioles dipped in hot water at 45°C was the most effective treatment in reducing the levels of microbial load which showed the lowest counts of microorganisms and inhibition of microorganisms 3.53 log CFU/g (average in the both seasons) followed by MAP at 5% O_2 + 5% CO_2 and dipping in hot water at 50°C treatments 4.11 and 4.01 log CFU/g (average of the two seasons respectively), with significant differences between them compared with the other treatments, while control had the highest value of microbial count 7.93 log CFU/g (average of the two seasons).

3.7. Polyphenol oxidase activity (PPO)

Table 5: Effect of some postharvest treatments on total chlorophyll (mg/100 g FW) of fresh-cut celery during storage at 0°C in 2021 and 2022 seasons.

2021						
	After 0 day	**After 4 days**	**after 8 days**	**after 12 days**	**after 16 days**	**mean**
45° C	36.95 A	34.11 B	31.20 C-E	29.00 E-G	27.00 G-J	**31.65 A**
50° C	36.95 A	31.23 CD	29.20 D-G	27.60 F-H	25.00 J-L	**30.00 B**
CO_2 5% + O_2 5%	36.95 A	31.60 C	29.80 C-F	28.00 F-H	25.10 I-L	**30.29 B**
CO_2 10%+ O_2 5%	36.95 A	29.00 EFG	27.20 G-J	26.00 H-K	23.00 LM	**28.43 C**
Chitosan	36.95 A	28.50 FG	27.80 F-H	25.20 I-L	23.50 LM	**28.39 C**
Control	36.95 A	27.30 G-I	24.40 KL	22.00 M	12.19 N	**24.57 D**
mean	**36.95 A**	**30.29 B**	**28.27 C**	**26.30 D**	**22.63 E**	
2022						
45° C	39.47 A	35.07 B	32.73 B-D	31.00 C-F	29.00 F-H	**33.45 A**
50° C	39.47 A	33.07 BC	31.13 C-F	30.00 E-G	27.00 H-J	**32.13 B**
CO_2 5% + O_2 5%	39.47 A	32.33 C-E	31.33 C-F	30.00 E-G	27.17 H-J	**32.06 B**
CO_2 10%+ O_2 5%	39.47 A	30.00 E-G	32.07 C-E	27.83 G-I	25.00 JK	**30.87 C**
Chitosan	39.47 A	30.33 D-G	29.83 E-G	27.00 H-J	25.00 JK	**30.33 C**
Control	39.47 A	29.00 F-H	25.67 I-K	24.00 K	14.50 L	**26.53 D**
mean	**39.47 A**	**31.63 B**	**30.46 C**	**28.31 D**	**24.61 E**	

Means in the same column having the same letter are not significantly different at 0.05 level by Duncan"s multiple rang test

Table 6: Effect of some postharvest treatments on total microbial count (CFU/g-1) of fresh-cut celery during storage at 0°C in 2021 and 2022 seasons.

2021						
	After 0 day	**After 4 days**	**after 8 days**	**after 12 days**	**after 16 days**	**mean**
45° C	0.12 Q	0.82 O	1.30 MN	2.50 I	3.80 F	**1.71 E**
50° C	0.26 PQ	1.04 NO	1.60 KL	3.33 G	4.10 E	**2.07 D**
CO_2 5% + O_2 5%	0.23 PQ	1.10 NO	1.80 K	2.58 I	4.40 D	**2.02 D**
CO_2 10%+ O_2 5%	0.32 PQ	1.62 KL	3.14 GH	4.22 DE	6.20 B	**3.10 B**
Chitosan	0.29 PQ	1.40 LM	3.00 H	4.00 EF	5.10 C	**2.76 C**
Control	0.42 P	2.14 J	4.22 DE	6.31 B	8.30 A	**4.28 A**
mean	**0.27 E**	**1.35 D**	**2.51 C**	**3.82 B**	**5.32 A**	
mean	**0.27 E**	**1.35 D**	**2.51 C**	**3.82 B**	**5.32 A**	
2022						
45° C	0.10 S	0.77 OP	1.17 MN	2.23 IJ	3.27 F	**1.51 E**
50° C	0.21 RS	0.68 PQ	1.48 KL	3.27 F	3.93 E	**1.92 D**
CO_2 5% + O_2 5%	0.23 RS	1.00 NO	1.57 K	2.47 HI	3.83 E	**1.82 D**
CO_2 10%+ O_2 5%	0.29 RS	1.42 K-M	2.67 GH	3.72 E	5.66 B	**2.75 B**
Chitosan	0.28 RS	1.25 L-N	2.80 G	3.90 E	4.63 D	**2.57 C**
Control	0.41 QR	2.03 J	3.94 E	5.23 C	7.57 A	**3.84 A**
mean	**0.25 E**	**1.19 D**	**2.27 C**	**3.47 B**	**4.82 A**	

Means in the same column having the same letter are not significantly different at 0.05 level by Duncan"s multiple rang test

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Table 7: Effect of some postharvest treatments on PPO (Unit/min.) of fresh-cut celery during storage at 0°C in 2021 and 2022 seasons.

2021						
	After 0 day	**After 4 days**	**after 8 days**	**after 12 days**	**after 16 days**	**mean**
45° C	39.40 T	41.20 S	44.60 Q	50.20 L	54.30 I	**45.94 F**
50° C	39.40 T	44.82 Q	48.30 N	53.00 J	59.00 E	**48.90 D**
CO_2 5% + O_2 5%	39.40 T	43.00 R	47.20 O	52.00 K	58.00 F	**47.92 E**
CO_2 10%+ O_2 5%	39.40 T	48.30 N	53.20 J	61.00 C	64.00 B	**53.18 B**
Chitosan	39.40 T	46.40 P	49.00 M	55.00 H	60.11 D	**49.98 C**
Control	39.40 T	49.00 M	55.61 G	60.22 D	67.81 A	**54.41 A**
mean	**39.40 E**	**45.45 D**	**49.65 C**	**55.24 B**	**60.54 A**	
2022						
45° C	37.83 J-L	34.93 L	35.00 L	36.30 L	39.47 J-L	**36.71 F**
50° C	37.83 J-L	37.73 KL	43.10 H-K	46.67 E-H	52.30 C-E	**43.53 D**
CO_2 5% + O_2 5%	37.83 J-L	37.63 KL	38.47 J-L	40.57 I-L	45.77 F-I	**40.05 E**
CO_2 10%+ O_2 5%	37.83 J-L	47.14 E-H	49.14 E-G	59.80 AB	55.33 B-D	**49.85 B**
Chitosan	37.83 J-L	42.77 H-K	45.63 F-I	51.17 D-F	57.57 A-C	**46.99 C**
Control	37.83 J-L	43.83 G-J	62.10 A	59.33 AB	62.33 A	**53.09 A**
mean	**37.83 E**	**40.67 D**	**45.57 C**	**48.97 B**	**52.13 A**	

Means in the same column having the same letter are not significantly different at 0.05 level by Duncan"s multiple rang test

Table 8: Effect of some postharvest treatments on phenolic (mg/ 100g F.W) of fresh-cut celery during storage at 0°C in 2021 and 2022 seasons.

2021						
	After 0 day	**After 4 days**	**after 8 days**	**after 12 days**	**after 16 days**	**mean**
45° C	31.11 A	29.20 B	27.40 E	25.12 I	21.70 L	**26.91 A**
50° C	31.11 A	28.70 C	26.00 FG	23.00 JK	20.30 N	**25.82 B**
CO_2 5% + O_2 5%	31.11 A	28.20 D	26.30 F	22.70 K	20.90 M	**25.84 B**
CO_2 10%+ O_2 5%	31.11 A	27.11 E	25.60 GH	20.11 N	18.00 P	**24.39 D**
Chitosan	31.11 A	27.00 E	25.40 HI	21.50 L	19.20 O	**24.84 C**
Control	31.11 A	26.13 F	23.20 J	19.11 O	15.22 Q	**22.95 E**
mean	**31.11 A**	**27.72 B**	**25.65 C**	**21.92 D**	**19.22 E**	
2022						
45° C	29.80 A	27.20 B	25.57 C	23.50 F	20.07 H	**25.23 A**
50° C	29.80 A	27.33 B	24.50 E	21.50 G	18.30 I	**24.29 B**
CO_2 5% + O_2 5%	29.80 A	27.67 B	24.80 DE	21.73 G	18.63 I	**24.53 B**
CO_2 10%+ O_2 5%	29.80 A	25.11 CD	23.27 F	18.73 I	16.08 K	**22.60 D**
Chitosan	29.80 A	25.57 C	23.63 F	20.17 H	17.30 J	**23.29 C**
Control	29.80 A	24.24 E	21.20 G	17.33 J	13.22 L	**21.16 E**
mean	**29.80 A**	**26.19 B**	**23.83 C**	**20.49 D**	**17.27 E**	

Means in the same column having the same letter are not significantly different at 0.05 level by Duncan"s multiple rang

Data in Table (7) indicate that the PPO activity of fresh-cut celery petioles increased significantly with the prolongation of the storage period during storage. All treatments reduced the activity of PPO during storage as compared with untreated control of fresh-cut celery petioles during storage. Fresh-cut celery petioles dipped in hot water at 45°C was the most effective treatment in delaying PPO activity during storage followed by MAP at 5% O_2 + 5% CO_2 and hot water at 50°C treatments with significant differences between them. However, MAP at 5% O_2 + 10% CO_2 treatment was less effective in this concern, while, control had a higher increase in the activity of PPO enzyme during storage. In preferred, the interaction between treatments and storage periods turned significant, after 16 days of storage at 0°C data revealed that fresh-cut celery petioles dipped in hot water at 45°C was reduced PPO activity by 53.23 units/min. (average in both seasons) compared with the other treatments or control 62.12 units/min. (average in both seasons).

3.8. Total phenolic content

Data in Table (8) indicate that the total phenolic content of fresh-cut celery petioles decreased significantly with the prolongation of storage periods. Regarding the effect of postharvest treatments, data revealed that fresh-cut celery petioles dipped in hot water at 45°C turned into the handiest treatment for reducing phenolic compounds loss during storage followed by MAP at 5% O_2 + 5% CO_2 and hot water at 50°C treatments with no significant differences between them during storage. While, MAP at 5% O_2 + 10% CO_2 and chitosan coating treatments were less effective in this concern with significant differences between them.
In preferred, the interaction among treatments and storage periods turned significant, after 16 days of storage at 0°C data revealed that fresh-cut celery petioles dipped in hot water at 45°C was the most effective treatment in maintaining the phenolic content of 20.88 mg/100g FW (average in both seasons) compared with the other treatments or control 14.22 mg/100g FW (average in both seasons).

3.9. Gas composition inside the packages:

Data in Tables (9 and 10) indicated that there was a significant decrease in O_2 % and an increase in CO_2 % in the packages of celery petioles during storage. Regarding the effect of postharvest remedies on gas composition within the programs, records discovered that there have been good-sized differences between postharvest treatments and untreated management. The gas composition inside the package treated with hot water at 45°C and 50°C treatments had high O_2 levels (17.91% and 16.91% average in both seasons respectively) and low CO_2 (3.21% and 3.53% average in both seasons respectively) with significant differences between them followed by chitosan at 0.5 % treatment.

4. Discussion

The result of this study revealed that dipped fresh-cut celery petioles in hot water at 45° and 50° C and chitosan at 0.5% and active modified atmosphere packaging (MAP) at 5% O_2 + 5% CO_2 and 5% O_2 + 10% CO_2 significantly enhanced the storability and maintained the quality parameters compared to passive MAP (control). However, fresh-cut celery petioles treated with hot water at 45° and 50° C and active MAP at 5% O_2 + 5% CO_2 were the most effective in reduced weight loss, colour changes, microbial content, polyphenol oxidase activity and maintained total phenolic content and general appearance. However, samples treated with hot water at 45° C showed the best quality avoiding the loss of green colour, retarded the growth of microorganisms, not exacted any browning in the cut surface of petioles, and did not exhibit any changes in general appearance till the end of storage period (16 days of storage at 0° C), while, hot water at 50° C and active MAP at 5% O_2 + 5% CO_2 rated good appearance at the same period. This result was true in the two seasons, and similar findings were confirmed by previous studies (Gómez and Artés, 2005, Grzegorzewskaa et al., 2022 and He and Luo, 2007).

The weight loss increase during storage as a result of the increase in respiration rate, metabolic process, and water loss (Amarante et al., 2001). Similar results were reported by Viña and Chaves (2003), (2007) and Zhan et al., (2013) on fresh cut celery. The obtained results detected that hot water, MAP and chitosan treatments decreased weight loss percentage during storage. This effect might be due to hot water treatment decreasing ethylene production and causing a delay in senescence, reducing the rate of respiration, and hence a reduction in weight loss during storage (Lemoine et al. (2009) and Perini et al (2017).
MAP and polypropylene bags make a unique role in conferment the moisture around the product and

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Table 9: Effect of some postharvest treatments on CO_2 % of fresh-cut celery during storage at 0°C in 2021 and 2022 seasons.

2021						
	After 0 day	**After 4 days**	**after 8 days**	**after 12 days**	**after 16 days**	**mean**
45° C	0.03 Q	0.60 P	1.20 NO	2.30 LM	3.30 K	**1.49 E**
50° C	0.03 Q	0.80 OP	1.30 N	2.50 L	3.60 K	**1.65 E**
CO_2 5% + O_2 5%	5.00 IJ	5.40 HI	5.90 FG	6.30 F	6.90 E	**5.90 B**
CO_2 10%+ O_2 5%	10.00 D	11.00 C	12.70 B	13.00 B	13.90 A	**12.12 A**
Chitosan	0.03 Q	1.00 N-P	3.50 K	4.83 J	5.80 GH	**3.03 D**
Control	0.03 Q	2.03 M	3.31 K	5.11 IJ	6.22 F	**3.34 C**
mean	**2.52 E**	**3.47 D**	**4.65 C**	**5.67 B**	**6.62 A**	
2022						
45° C	0.03 N	0.53 M	1.07 KL	2.10 J	3.13 I	**1.37 E**
50° C	0.03 N	0.73 LM	1.23 K	2.33 J	3.47 I	**1.56 E**
CO_2 5% + O_2 5%	5.00 GH	5.07 GH	5.37 FG	6.23 E	6.73 D	**5.68 B**
CO_2 10%+ O_2 5%	10.00 C	10.17 C	12.43 B	12.23 B	13.17 A	**11.60 A**
Chitosan	0.03 N	0.97 K-M	3.35 I	4.80 H	5.67 F	**2.96 D**
Control	0.03 N	2.01 J	3.10 I	5.10 GH	6.17 E	**3.28 C**
mean	**2.52 E**	**3.25 D**	**4.43 C**	**5.47 B**	**6.39 A**	

Means in the same column having the same letter are not significantly different at 0.05 level by Duncan"s multiple rang

Table 10: Effect of some postharvest treatments on O_2 of fresh-cut celery during storage at 0°C in 2021 and 2022 seasons.

2021						
	After 0 day	**After 4 days**	**after 8 days**	**after 12 days**	**after 16 days**	**mean**
45° C	20.70 A	20.00 B	19.60 C	19.00 D	18.00 F	**19.46 A**
50° C	20.70 A	19.60 C	19.00 D	18.00 F	17.00 H	**18.86 B**
CO_2 5% + O_2 5%	3.00 M	2.86 MN	2.61 NO	2.40 O-Q	2.14 QR	**2.60 E**
CO_2 10%+ O_2 5%	3.00 M	2.50 OP	2.30 P-R	2.08 RS	1.84 S	**2.34 F**
Chitosan	20.70 A	18.60 E	17.90 F	16.50 I	15.60 J	**17.86 C**
Control	20.70 A	17.30 G	15.80 J	14.00 K	12.30 L	**16.02 D**
mean	**14.80 A**	**13.48 B**	**12.87 C**	**12.00 D**	**11.15 E**	
2022						
45° C	20.70 A	19.67 B	19.40 BC	18.67 D	17.83 E	**19.25 A**
50° C	20.70 A	19.27 C	18.83 D	17.83 E	16.83 F	**18.69 B**
CO_2 5% + O_2 5%	3.00 K	2.80 K	2.43 L	2.27 LM	2.07 M	**2.51 E**
CO_2 10%+ O_2 5%	3.00 K	2.30 LM	2.10 LM	2.00 MN	1.70 N	**2.22 F**
Chitosan	20.70 A	18.50 D	17.70 E	16.27 G	15.33 H	**17.70 C**
Control	20.70 A	17.00 F	15.50 H	13.83 I	12.20 J	**15.85 D**
mean	**14.80 A**	**13.26 B**	**12.66 C**	**11.81 D**	**10.99 E**	

Means in the same column having the same letter are not significantly different at 0.05 level by Duncan"s multiple rang

therefore lowest weight loss. This increases the relative humidity and reduces vapour pressure deficit and transpiration. On the other hand, polypropylene bags create a MAP with reduced oxygen and increase carbon dioxide concentration around the product which decreases the weight loss percentage by slowing down the metabolic processed and transpiration (Gómez and Artés, 2005).

Low weight loss and maintained quality and storability from chitosan treatment are due to a semipermeable film on the surface of celery petioles that can be formed by the chitosan, consequently modifying the internal atmosphere of the petioles with limited gas exchanges due to the coating barriers, enzymatic activity and metabolism in evolving respiration (Raymond et al., 2012).

The general appearance of celery petioles decreased during storage periods and this may be due to shrivelling, wilting, colour changes, and decay (Velickova et al., 2013). The preservation of the general appearance of celery treated with hot water, MAP, and chitosan may be due to, hot water, Loaiza-Velarde and Saltveit (2001) found that hot water was effectively acting as antioxidants enzymes of celery and this could reduce the deterioration, physiological disorders and enhance the resistance of tissue against microbial growth and reduce the spoilage of product (Loaiza-Velarde and Saltveit, 2001).

Akbudak (2008) found that MAP´s slower physiological processes in celery and lower incidence of spoilage in this celery may be explained by the retention of celery quality through MAP in terms of water loss. Velickova et al. (2013) stated that chitosan coating acts as a semipermeable barrier at the surface of fruit and vegetables against oxygen, carbon dioxide, and moisture, thereby reducing respiratory, water loss, respiration pastime and degradation via enzymes and microbial rot of fruits, counteracting the dehydration and shrinkage of the fruit, and ethylene manufacturing and keeping the generally great and prolongation the shelf existence.

Colour is one of the main visual quality criteria that influence whether or not consumers would accept fresh products. To assess the colour change that happens in the product across all storage periods. The colour parameter L value (Lightness) was measured. The L value represented the visual appearance of the product by indicating the brightness or darkness of the celery surface (Gómez and Artés, 2005). With increasing storage period, the L value of celery declined dramatically and a slight yellowness occurred on the surface of the celery. A reduction in the L value indicated that the surface is darkening (Velickova et al., 2013). Ardiakani and Mostofi (2019) showed that decreasing L value is related to water loss of products.

The results showed that all postharvest treatments had significantly higher L values compared with the control. That result is in agreement with Saltveit and Mangrich (1996) and Gómez and Artés (2005).
The faster increase in the yellow colour of celery p

etioles in passive MAP is due to excess O_2 that causes enzymatic browning (Loaiza-Velarde et al. (2003) and Kobayashi et al. (2021). Celli et al. (2018), Xing et al. (2011), and Xing et al. (2019) reported that chitosan-coated slightly lightened as evidenced by an increase in L value.

The obtained result indicated that there is an increase in discolouration (score) of the celery petioles with the extension of the storage period. These results are in agreement with Gómez and Artés (2005). The change in colour development is related primarily to the oxidation of phenolic compounds to o-quinone a reaction catalysed by PPO. Quinone is polymerized into dark brown, black or red polymers (Saleh et al., 2013).

The reduction of discolouration on the cut surface of celery petioles treated with hot water or MAP may be due to those treatments reducing PPO and preserving the total phenolic content. So, this treatment makes a reduction of colour change in the cut surface (Loaiza-Velarde et al. (2003) for hot water and Gómez and Artés (2005) and Kobayashi et al. (2021) for MAP on fresh-cut celery petioles).

Furthermore, the total chlorophyll content of celery petioles decreases with increasing storage period, this may be due to a gradual increase in the degradation of chlorophyll and the conversion of chloroplasts in to chromoplasts caused by the activity of the chlorophylase (He and Luo, 2007). Those outcomes are in

ISSN-Internet 2197-411x OLCL 862804632

settlement Kader (1986), Velickova et al. (2013) and Qi et al. (2011) for hot water and Gómez and Artés (2005) for MAP and Xing et al. (2011) and Xing et al. (2019) for chitosan.

The reduction in chlorophyll loss during storage in the celery petioles treated with hot water, MAP, and chitosan treatments might be due to the effect of these treatments on the physiological processes involved in the degradation of chlorophyll (decreased activity of chlorophyllase and consequence reduced colour change (Loaiza-Velarde et al. (2003) on celery petioles).

Also, Loaiza-Velarde et al. (2003) and Gómez and Artés (2005) reported that celery petioles stored at MAP reduce the breakdown of chlorophyll to phaeophytin during storage.

The obtained results showed that hot water, MAP and chitosan treatments had lower levels of microbial load in comparison to control. These results are in agreement with Chan et al. (1989) for hot water, Nielsen and Leufven (2008) for MAP and Fang et al. (1994) for chitosan. The previous results have demonstrated that celery petioles stored at active MAP (6% O_2 + 7% CO_2) reduced mesophilic and psychrotrophic growth during storage. Also, the active MAP apparently behind-schedule fruit senescence and inhibited microbial increase, and controlled the exponential boom of microbial microorganisms (Nielsen and Leufven, 2008).

Dipping the samples in hot water led to some decrease in fungal development may be associated with the washing off of a number of natural pathogenic spore populace from the surface of the fruits. However, one of these dip may additionally get rid of a part of the herbal opposed flowers inhibiting the fruit peel which may act as a bio manage agent of postharvest pathogens (Chan et al. (1989) on cucumber). Farber (1991) found that CO_2 inhibits microbial hobby in two methods, it dissolves in water in the product, and it has a poor impact on enzymatic and biochemical sports in cells of each product and microorganisms.

The antimicrobial of chitosan is probably caused by the interaction between chitosan and the microbial cell membranes, which leads to the leakage of proteinaceous and other intracellular constituents. Chitosan can penetrate the nuclei of fungi cell and interferes with RNA and protein synthesis (Rabean et al., 2003). Also, this was probably due to the fungicidal action of chitosan that caused alteration in the function of the cellular membrane of fungal cells (Fang et al., 1994).

Chitosan has the ability to resist several fungi and induce defence enzymes such as chitinase and chitosanase, which are associated with induced systemic resistance of fruits (Irkin et al., 2014).

The obtained results showed that the polyphenol oxidase (PPO) activity of fresh-cut celery increased with the prolongation of the storage period during storage. The increase of PPO activity in celery petioles after slicing is in particular because of the activation technique from latent to absolutely lively form. In fact, as previously stated by Cantos et al. (2001) tissue wounding includes the decompart metallization of cellular additives with the following launch of proteases related to a cascade of reactions main to the activation of latent PPO.

The reduction of PPO activity of fresh cut of celery treated with hot water, MAP, and chitosan may be due to these treatments, reduced respiration rate and which provides a decrease in metabolic activities and suppresses the enzyme activities during storage Loaiza-Velarde et al. (2003) for hot water and Gómez and Artés (2005) for MAP and Qi et al. (2011) for chitosan.

Hot water treatment reduced enzymes activities (PPO, PG, and Cellulase) and enzymes related ripening of fruit (Viña and Chaves, 2007). Active MAP reduces enzyme activity due to a decrease in O_2 and an increase in CO_2 concentration in the headspace surrounding the product (Gómez and Artés, 2005).

The inhibitory effect of chitosan remedy on PPO interest might be due to a low O_2 availability in the sweet cherry fruit (Qi et al., 2011). The reduction in skin and flesh shade adjustments is because of the upkeep of cell compartmentalization and separation of PPO and POD enzymes from their phenolic substrates. Similarly inhibited POD and PPO sports had been found in response to opportunity technology to chitosan coating hired on unique fruit to enhance

their postharvest shelf life (Zhang et al., 2015).
Phenolic compounds are responsible for most of the antioxidant activity in products making them a natural source of antioxidants (He and Luo, 2007). The decrease in total phenolic content with the prolongation of storage periods may be due to phenolic compounds having a significant role in oxidation processes as antioxidants and as substrates in browning reactions. During storage, the enzymatic oxidation is continued and the resulting quinones are polymerized non-enzymatically to give darker pigments, which explain the parallel consumption of phenols with the development of blackness throughout the storage period (Robards et al., 1999).

All postharvest treatments reduced the loss of total phenolic content compared with control during storage. These results were in agreement with He and Luo (2007) and Loaiza-Velarde et al. (2003) for hot water and MAP and Jongsri et al. (2016) for chitosan.

MAP maintained higher total phenolic content because of the reduction of processes. MAP with low O_2 and high CO_2 was the most effective for retaining total antioxidant activity and total phenolic throughout the storage period (Grzegorzewskaa et al. (2022) in hot water).
Chitosan has been reported to increase the potential of the reactive oxygen species scavengers, leading to increased contents of phenolic compounds and antioxidants (Jongsri et al., 2016). Also, treatment with different concentrations of chitosan has also been reported to activate the antioxidant enzymes catalase (CAT), superoxide dismutase (SOD), and peroxidase (POD), which are an important part of the antioxidant potential during storage, in tomatoes (Liu et al., 2007) and guava (Hong et al., 2012).

Increasing the CO_2 concentration around the product may be promoting the synthesis and accumulation of phenolic as a physiological reaction. CO_2 storage had marked effects on phenolic metabolites while MAP had a nice effect on phenolic-associated quality (Tomás-Barberán and Espin, 2003). High CO2 may also allow for the removal of free radicals, which might be related to preserving antioxidant capability (Wang et al., 2003).
The obtained results indicated that there was a significant decrease in O_2% and an increase in CO_2% in the package of celery petioles during storage. Similar results were obtained by Viña and Chaves (2003) and Cantwell and Suslow (2002) on fresh-cut celery. They may be due to O_2 consumption and CO_2 production of fruits during the respiration process (Ubhi et al., 2014). The high O_2% and low CO_2% inside the packages of MAP, chitosan, and hot water may be due to reduced and decrease respiration rate and consequently reduced consumption of O_2 and accumulation of CO_2 levels inside the bags (Gómez and Artés (2005) on MAP, Jongsri et al. (2016) for chitosan, and Kobayashi et al. (2021) for hot water).

5.Conclusion

Fresh-cut celery petioles dipped in hot water at 45° C for one min. showed the best quality avoided the loss of green colour, retarded the growth of microorganisms, not exacted any browning in the cut surface of petioles, and did not exhibit any changes in general appearance.

Conflict of Interest

The authors declare no conflict of interest. Besides, the funders had no role in the design of the study; in the collection, analysis, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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