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Effect of some postharvest treatments on quality attributes and storability of asparagus spears during cold storage

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Abstract

This study was conducted during 2022 and 2023 seasons to evaluate the influence of sheet contained 5% 1-MCP, exposed to ozone gas (4 or 7 ppm), active MAP (5% O_2 + 5% CO_2 or 5% O_2 + 10% CO_2) and passive MAP as compared with untreated control on quality attributes and storability of asparagus spears (UC157 F_2) during storage at 2°C and 90-95% RH for 20 days. Results indicated that asparagus spears treated with all postharvest treatments were effective in reducing weight loss %, curvature, Phenylalanine ammonia-lays enzyme activity, discoloration, colour change, O_2 consumption and CO_2 production as well as in maintaining total chlorophyll, total phenolic and the overall appearance of spears during storage as compared with untreated control. However, asparagus spears treated with ozone gas at 4 ppm were the most effective treatment in preserving all the quality attributes of spears. Furthermore, this treatment showed the excellent appearance of spears without any discoloration and curvature till 20 days of storage while ozone gas (7 ppm), 1-MCP and active MAP (5% O_2 + 5% CO_2) treatments gave a good appearance at the same period. The gas composition inside the package treated with ozone gas at 4 or 7 ppm had high O_2 and low CO_2 %.

Key words: Asparagus spears, ozone gas, 1-methylcyclopropane, active MAP, cold storage, PAL enzyme.

Introduction

Asparagus officinalis L., green asparagus, is loved for its strong flavour and nutritional value. The high concentration of phenolic compounds in these delicate spears, especially flavonoids with antioxidant properties, is notable (Zhang, 2019). Mangaraj and Goswami (2009) noted that fresh asparagus' high respiration rate and metabolic activity make it susceptible to senescence. According to Wang and Fang (2019), these spears toughen, develop unpleasant odours, lose moisture through transpiration, degrade chlorophyll, and change their total phenolic content during storage.

With its natural negative geotropic growth curvature (Poyesh *et al.*, 2017), green asparagus can lose its freshness and visual appeal, lowering its quality rating (Anon, 1986). Lignification is a key factor in green asparagus quality, emphasising the need for improved postharvest storage methods that benefit consumers and the asparagus industry.

The utilization of a modified atmosphere packaging (MAP) system, involving a specific gas mixture and permeable polymeric films/packages, serves to decelerate respiration activity and prolong the asparagus's shelf life. This approach helps preserve the quality of asparagus (Wang *et al.*, 2020). The ambient gas levels during postharvest storage are crucial as they directly impact respiration rates and physiological changes. In the case of fresh asparagus, the minimum tolerable O_2 concentration is 5%, while the maximum permissible CO_2 concentration is 10% (Kader, 2002). The MAP method effectively maintains the freshness and extends the shelf life of fresh asparagus by influencing both microbial populations and chemical degradation (Benyathiar *et al.*, 2020).

Ozone (O_3) naturally decomposes into oxygen and has garnered attention as a postharvest technology for controlling spoilage in fruits and vegetables due to its safety and lack of residue in treated products (Hua-lia *et al.*, 2019). Ozone application can induce hormesis in fruits and vegetables, promoting positive physiological responses such as the synthesis of antioxidants, polyamines, phenolic compounds, and other secondary metabolites (Pretell *et al.*, 2016). Additionally, Pretell-Vasquez *et al.* (2020) demonstrated the significant impact of gaseous ozone at 6.98 ppm on maintaining firmness, chlorophyll content, and lignin content of green asparagus during storage at 1°C. Furthermore, the application of gaseous ozone at 10 ppm serves as a functional postharvest technology that preserves key quality attributes, including overall appearance and total phenol content, allowing for a shelf life of 26 days at 1°C (Pretell-Vasquez *et al.*, 2021).

Another noteworthy method for enhancing the postharvest quality of asparagus is the application of 1-methylcyclopropene (1-MCP). This gaseous substance plays a crucial role in delaying ripening and senescence processes by inhibiting ethylene binding to active sites, resulting in delayed colour development, enhanced firmness, and reduced ethylene production in tomato fruit (Sabir *et al.*, 2012). Poyesh *et al.* (2017) proposed that 1-MCP can effectively maintain the quality of asparagus spears during storage under ambient conditions. Moreover, when asparagus spears are treated with 1-MCP and stored horizontally, they exhibit reduced upward growth, suggesting the potential to improve postharvest quality. The combination of modified atmosphere storage and 1-MCP treatment leads to reduced fresh weight loss rates and the highest visual quality values, while also minimizing off-flavors, soluble solid content, and hue angle in asparagus spears after 20 days of storage. Ethylene content is notably lower when employing the MA storage with 1-MCP treatment (Yoon *et al.*, 2016).

It's important to note that asparagus spears are often transported and stored in a horizontal position. However, this horizontal storage can lead to upward growth due to negative geotropism, resulting in energy loss and a decline in freshness. With this in mind, the current investigation aims to assess whether treatments involving 1-MCP, ozone gas, active MAP, and passive MAP can mitigate this phenomenon and influence the upward growth angle of horizontally stored asparagus.

Materials and methods

Fresh green asparagus spears, meeting stringent quality criteria, were harvested in their prime on January 2, 2022, and January 4, 2023, from an Egyptian commercial farm. They were swiftly transported to the Vegetable Handling Research Department, Horticultural Research Institute, Agricultural Research Center, within a 3-hour window from harvest.

Selected spears, straight, undamaged, 15-19 mm in diameter, approximately 25 cm long, with closed bracts and injury-free, were arranged in trays of about seven spears each. These trays were packed in carton boxes (25 x 30 x 10 cm) and enclosed with a 40µ polyethylene film, forming an experimental unit (EU). The spears were subjected to diverse treatments, including exposure to 1-methylcyclopropane sheets (5%), ozone gas (4 or 7 ppm), active MAP (5% O_2 + 5% CO_2 or 5% O_2 + 10% CO_2), passive MAP, and a control group.

Each treatment comprised eighteen EUs, which were weighed, labeled, and stored horizontally at 2°C and 90-95% relative humidity for 20 days. This study employed a completely randomized factorial design with three replicates (EUs), with measurements conducted at harvest and 4-day intervals (0, 4, 8, 12, 16, and 20 days) to assess various properties.

Weight loss (%): It was calculated according to the equation: = [(initial weight of spears – weight of spears at sampling data)/ (initial weight of spears)] x100**.**

General appearance: It was evaluated using a scale from 9 to 1, were 9= excellent, 7= good, 5= fair, 3= poor, 1= unsalable (Kader *et al.*, 1973).

Curvature: For this, a scale of 1 to 5 was used, where 1, non; 2, slight (curvature of stem or leaf up to 15° from the horizontal); 3, moderate (15-30°); 4, severe (30-45°) and 5, extra severe (> 45° from the horizontal).

Color: Colors of spears were measured by using colorimeter Minolta, Ramsey, N. J. Model DP9000 witch measure (L* value) L* refers to the lightness, ranging from 0= black to 100=white (Mc Guire, 1992).

Gas composition inside the packages: The concentrations of O_2 and CO_2 inside the packages were monitored using Dual Trak model 902 D gas analyzer. By inserting the test probe through a rubber seal attached to the outside of the packaging.

Total chlorophyll content: It was determined according to AOAC, 1990.

Phenylalanine ammonia-lyase: The PAL activity was measured according to the method of Cheng and Breen (1991).

Discoloration: Was evaluated on a scale of 1 to 5, were 1= non, 2= slight, 3= moderate, 4= severe, and 5= extra severe, as described by Cantwell *et al.* (2009).

Total phenolic content: Was determined according to Singleton *et al.* (1999).

Statistical analysis: Data were statistically analyzed using the analysis of variance (Snedecor and Cochran, 1980). Duncan multiple range test was applied for the comparison between means according to Waller and Duncan (1969).

Results and discussion

Weight loss*:* Weight loss in asparagus spears increased significantly with prolonged storage in both seasons (Table 1). This increase was attributed to respiration and senescence-related metabolic processes (Amarante *et al.*, 2001). Similar results were reported by Hussein (2021). Postharvest treatments effectively reduced weight loss during storage. Ozone gas at 4 ppm was the most effective treatment, followed by ozone gas at 7 ppm and 1-methylcyclopropane (1-MCP) at 5%. Passive modified atmosphere packaging (MAP) and active MAP at 5% O_2 + 10% CO_2 were less effective, showing significant differences in the two seasons. Control spears had the highest weight loss. These findings are in agreement with previous studies (Ibrahim and Abdullah, 2018; Poyesh *et al.*, 2018; Benyathiar *et al.*, 2020; Pretell-Vasquez *et al.*, 2020; Wang *et al.*, 2020).

Minimizing weight loss through ozone or 1-MCP treatments was attributed to their ability to remove or absorb exogenous ethylene, which reduced the respiration rate (Wang *et al.*, 2020). Lower weight loss in MAP-treated spears was due to the creation of a modified atmosphere

Table 1. Effect of 1-methylcyclopropane, ozone and modified atmosphere packaging treatments and storage period on weight loss (%) of asparagus spears during cold storage in 2022 and 2023 seasons

Treatment	0	4	8	12	16	20	Mean
				First season			
1-methylcyclopropane 5%	0.00 v	0.14 tu	0.38 pq	0.48 n-p	0.60 l-n	0.78 jk	0.40 E
Ozone 4 ppm	0.00 v	0.10 uv	0.22 s-u	0.29 q-s	0.42 o-q	0.54 m-o	0.26 F
Ozone 7 ppm	0.00 v	0.13 t-v	0.37 p-r	0.46 op	0.55 m-o	0.71 kl	0.37 E
MAP (5% O_2 and 5% CO_2)	0.00 v	0.15 s-u	0.43 op	0.60 l-n	0.74 k	0.92 g-i	0.47 D
MAP (5% O_2 and 10% CO_2)	0.00 v	0.24 r-t	0.66 k-m	0.79 i-k	0.95 gh	1.16 f	0.63 B
Passive MAP	0.00 v	0.18 s-u	0.50 n-p	0.70 kl	0.88 h-j	1.03 g	0.55 C
Control	0.00 v	2.37 e	4.85 d	7.50 c	8.55 b	10.45 a	5.62 A
Mean	0.00 F	0.47 E	1.06 D	1.55 C	1.81 B	2.23 A	
				Second season			
1-methylcyclopropane 5%	0.00 y	0.12 x	0.33 r-t	0.45 o-q	0.57 mn	0.77 jk	0.37 E
Ozone 4 ppm	0.00 y	0.06 xy	0.16 v-x	0.25 t-v	0.40 p-s	0.50 n-p	0.23 F
Ozone 7 ppm	0.00 y	0.11 x	0.32 s-u	0.43 o-r	0.52 m-o	0.69 j-l	0.34 E
MAP (5% O_2 and 5% CO_2)	0.00 y	0.13 wx	0.37 q-s	0.57 mn	0.73 jk	0.89 h	0.45 D
MAP (5% O_2 and 10% CO_2)	0.00 y	0.22 u-w	0.61 lm	0.77ij	0.93 gh	1.12 f	0.61 B
Passive MAP	0.00 y	0.15 wx	0.44 o-q	0.67 kl	0.87 hi	1.00 g	0.52 C
Control	0.00 y	2.20 e	4.66 d	7.33 c	8.36 b	10.38 a	5.49 A
Mean	0.00 F	0.43 E	0.98 D	1.50 C	1.77 B	2.19 A	

Values with the same letter(s) are not significantly different at $P \leq 0.05$ level; using Tukey's multiple range test.

Table 2. Effect of 1-methylcyclopropane, ozone and modified atmosphere packaging treatments and storage period on general appearance (score) of asparagus spears during cold storage in 2022 and 2023 seasons

Treatment	0	4	8	12	16	20	Mean
				First season			
1-methylcyclopropane 5%	9.00 a	9.00 a	9.00 a	9.00 a	8.33 ab	7.00 cd	8.56 AB
Ozone 4 ppm	9.00 a	9.00 a	9.00 a	9.00 a	9.00 a	8.33 ab	8.89 A
Ozone 7 ppm	9.00 a	9.00 a	9.00 a	9.00 a	8.33 ab	7.67 bc	8.67 AB
MAP (5% O_2 and 5% CO_2)	9.00 a	9.00 a	9.00 a	8.33 ab	7.67 bc	7.00 cd	8.33 B
MAP (5% O_2 and 10% CO_2)	9.00 a	7.67 bc	7.00 cd	6.33 de	5.67 ef	5.00 fg	6.78 D
Passive MAP	9.00 a	8.33 ab	7.67 bc	7.00 cd	6.33 de	5.67 ef	7.33 C
Control	9.00 a	4.33 gh	3.67 hi	3.00 i	1.67 j	1.00 j	3.78 E
Mean	9.00 A	8.05 B	7.76 BC	7.38 C	6.71 D	5.95 E	
				Second season			
1-methylcyclopropane 5%	9.00 a	9.00 a	9.00 a	9.00 a	8.33 ab	7.00 cd	8.56 AB
Ozone 4 ppm	9.00 a	9.00 a	9.00 a	9.00 a	9.00 a	8.33 ab	8.89 A
Ozone 7 ppm	9.00 a	9.00 a	9.00 a	9.00 a	8.33 ab	7.67 bc	8.67 AB
MAP (5% O_2 and 5% CO_2)	9.00 a	9.00 a	9.00 a	8.33 ab	7.67 bc	7.00 cd	8.33 BC
MAP (5% O_2 and 10% CO_2)	9.00 a	8.33 ab	7.67 bc	7.00 cd	6.33 de	5.67 ef	7.33 D
Passive MAP	9.00 a	9.00 a	8.33 ab	7.67 bc	7.00 cd	6.33 de	7.89 C
Control	9.00 a	5.00 fg	4.33 gh	3.67 h	2.33 i	1.67 i	4.33 E
Mean	9.00 A	8.33 B	8.05 BC	7.67 C	7.00 D	6.24 E	

Values with the same letter(s) are not significantly different at $P \leq 0.05$ level; using Tukey's multiple range test.

Table 3. Effect of 1-methylcyclopropane, ozone and modified atmosphere packaging treatments and storage period on curvature (score) of asparagus spears during cold storage in 2022 and 2023 seasons

Treatment	0	4	8	12	16	20	Mean
				First season			
1-methylcyclopropane 5%	1.00 h	1.00 h	1.00 h	1.00 h	1.00 h	2.00 ef	1.17 D
Ozone 4 ppm	1.00 h	1.00 h	1.00 h	1.00 h	1.00 h	1.00 h	1.00 E
Ozone 7 ppm	1.00 h	1.00 h	1.00 h	1.00 h	1.00 h	1.00 h	1.00 E
MAP (5% O_2 and 5% CO_2)	1.00 h	1.00 h	1.00 h	1.00 h	1.00 h	2.00 ef	1.17 D
MAP (5% O_2 and 10% CO_2)	1.00 h	1.00 h	1.00 h	1.33 gh	2.00 ef	2.67 cd	1.50 B
Passive MAP	1.00 h	1.00 h	1.00 h	1.00 h	1.67 fg	2.33 de	1.33 C
Control	1.00 h	1.67 fg	2.00 ef	3.00 c	4.33 b	5.00 a	2.83 A
Mean	1.00 E	1.10 DE	1.14 D	1.33 C	1.71 B	2.29 A	
				Second season			
1-methylcyclopropane 5%	1.00 g	1.00 g	1.00 g	1.00 g	1.00 g	1.67 ef	1.11 CD
Ozone 4 ppm	1.00 g	1.00 g	1.00 g	1.00 g	1.00 g	1.00 g	1.00 D
Ozone 7 ppm	1.00 g	1.00 g	1.00 g	1.00 g	1.00 g	1.00 g	1.00 D
MAP (5% O_2 and 5% CO_2)	1.00 g	1.00 g	1.00 g	1.00 g	1.00 g	1.67 ef	1.11 CD
MAP (5% O_2 and 10% CO_2)	1.00 g	1.00 g	1.00 g	1.33 fg	2.00 de	2.33 cd	1.44 B
Passive MAP	1.00 g	1.00 g	1.00 g	1.00 g	1.67 ef	2.00 de	1.28 BC
Control	1.00 g	1.33 fg	1.67 ef	2.67 c	4.00 b	4.67 a	2.56 A
Mean	1.00 D	1.05 D	1.10 D	1.29 C	1.67 B	2.05 A	

Values with the same letter(s) are not significantly different at $P \leq 0.05$ level; using Tukey's multiple range test.

with higher CO_2 and reduced O_2, which decreased respiration rate and metabolic processes (Techavuthiporn and Boonyaritthongchai, 2016). The interaction between postharvest treatments and storage periods was significant in both seasons.

General appearance*:* General appearance significantly decreased with prolonged storage (Table 2) due to factors such as slight dryness and colour changes (Qiu *et al.*, 2013). All postharvest treatments improved the general appearance of asparagus spears compared to the untreated control. Ozone gas at 4 or 7 ppm and 1-MCP at 5% were the most effective treatments, with no significant differences between them. Active MAP at 5% O_2 + 5% CO_2 also had a positive impact, while active MAP at 5% O_2 + 10% CO_2 was less effective, and control had the lowest scores. These findings align with previous research (Aday *et al.*, 2014; Yoon *et al.*, 2016; Gad El-Rab, 2018; Ibrahim and Abdullah, 2018; Benyathiar *et al.*, 2020).

Ozone was found to maintain postharvest fruit quality by oxidizing ethylene, reducing the respiration rate, and extending the shelf life (Mshraky, 2017). Ozone and/or MAP treatments inhibited the increase in PAL activity, contributing to the maintenance of overall visual fruit quality (Loaiza-Velarde and Saltveit, 2001). The improvement in general appearance resulting from 1-MCP treatment was attributed to its effects on weight loss, rot rate reduction, and delayed ripening (Ibrahim and Abdullah, 2018). MAP was effective in slowing physiological processes in asparagus spears, reducing spoilage incidence, and decreasing sensitivity to ethylene, as well as slowing the loss of chlorophyll, texture, and off-odor during storage (Wang *et al.*, 2020). The interaction between postharvest treatments and storage periods was significant in both seasons, with the best appearance observed in spears treated with ozone gas at 4 ppm after 20 days of storage at 2°C.

Curvature*:* Spear curvature increased significantly during storage (Table 3) due to negative geotropism, especially when spears were placed

Table 4. Effect of 1-methylcyclopropane, ozone and modified atmosphere packaging treatments and storage period on colour (L value) of asparagus spears during cold storage in 2022 and 2023 seasons

Treatment	0	4	8	12	16	20	Mean
				First season			
1-methylcyclopropane 5%	47.23a	46.68a-c	44.85a-h	43.42f-k	42.60h-l	41.30k-n	44.35BC
Ozone 4 ppm	47.23a	47.08ab	46.70a-c	46.03a-e	45.75a-f	44.26c-j	46.18A
Ozone 7 ppm	47.23a	46.82ab	45.27a-g	44.30c-j	43.66e-k	42.15j-l	44.90B
MAP (5% O_2 and 5% CO_2)	47.23a	46.57a-d	44.73b-i	43.12g-l	42.27i-l	40.74l-o	44.11BC
MAP (5% O_2 and 10% CO_2)	47.23a	45.66a-f	43.37f-k	41.92j-m	40.65l-o	38.55op	42.90D
Passive MAP	47.23a	46.20a-d	44.11d-j	42.05j-m	41.33k-n	39.39no	43.39CD
Control	47.23a	42.85g-l	39.58m-o	36.46p	32.67q	26.33r	37.52E
Mean	47.23A	45.98B	44.09C	42.47D	41.28E	38.96F	
				Second season			
1-methylcyclopropane 5%	53.46a	52.96ab	51.18b-f	49.68e-j	48.77g-n	47.55k-o	50.60B
Ozone 4 ppm	53.46a	53.31a	52.97ab	52.26a-c	51.94a-c	50.49c-h	52.40A
Ozone 7 ppm	53.46a	53.03ab	51.58a-e	50.51c-g	49.77d-j	48.37h-n	51.12B
MAP (5% O_2 and 5% CO_2)	53.46a	52.83ab	51.05b-f	49.38f-l	48.44g-n	47.00m-o	50.36BC
MAP (5% O_2 and 10% CO_2)	53.46a	51.86a-d	49.65e-k	48.12j-n	46.80n-p	44.75pq	49.10D
Passive MAP	53.46a	52.41a-c	50.37c-i	48.26i-n	47.45l-o	45.59op	49.59CD
Control	53.46a	49.11f-m	45.93op	42.73q	38.82r	32.60s	43.78E
Mean	53.46A	52.22B	50.39C	48.70D	47.43E	45.19F	

Values with the same letter(s) are not significantly different at $P \leq 0.05$ level; using Tukey's multiple range test.

Table 5. Effect of 1-methylcyclopropane, ozone and modified atmosphere packaging treatments and storage period on O_2 (%) of asparagus spears during cold storage in 2022 and 2023 seasons

Treatment	0	4	8	12	16	20	Mean
				First season			
1-methylcyclopropane 5%	20.80 a	20.20 bc	18.97 f	17.27 i	16.10 k	15.07 m	18.07 D
Ozone 4 ppm	20.80 a	20.47 b	20.17 bc	19.60 e	18.37 g	17.73 h	19.52 B
Ozone 7 ppm	20.80 a	20.32 bc	19.85 de	19.23 f	17.90 h	16.97 i	19.18 C
MAP (5% O_2 and 5% CO_2)	5.00 o	4.63 p	4.23 q	3.63 r	2.70 s	1.97 tu	3.69 F
MAP (5% O_2 and 10% CO_2)	5.00 o	4.07 q	3.70 r	2.95 s	2.15 t	1.84 u	3.28 G
Passive MAP	20.80 a	20.13 cd	18.23 g	16.43 j	15.70 l	14.57 n	17.64 E
Control	20.80 a	20.80 a	20.80 a	20.80 a	20.80 a	20.80 a	20.80 A
Mean	16.29 A	15.80 B	15.14 C	14.27 D	13.39 E	12.71 F	
				Second season			
1-methylcyclopropane 5%	21.00 a	20.43 bc	19.10 fg	17.45 j	16.35 k	15.38 l	18.29 D
Ozone 4 ppm	21.00 a	20.70 ab	20.42 bc	19.90 de	18.70 gh	18.08 i	19.80 B
Ozone 7 ppm	21.00 a	20.57 a-c	20.12 cd	19.53 ef	18.23 i	17.32 j	19.46 C
MAP (5% O_2 and 5% CO_2)	5.00 n	4.67 no	4.30 op	3.68 q	2.73 r	2.03 s	3.74 F
MAP (5% O_2 and 10% CO_2)	5.00 n	4.10 pq	3.73 q	3.00 r	2.23 s	1.87 s	3.32 G
Passive MAP	21.00 a	20.30 b-d	18.33 hi	16.57 k	15.83 l	14.67 m	17.78 E
Control	21.00 a	21.00 a	21.00 a	21.00 a	21.00 a	21.00 a	21.00 A
Mean	16.43 A	15.97 B	15.29 C	14.45 D	13.58 E	12.91 F	

Values with the same letter(s) are not significantly different at $P \leq 0.05$ level; using Tukey's multiple range test.

horizontally (Paull and Chen, 1999). Postharvest treatments effectively reduced curvature compared to the control. Ozone gas at 4 or 7 ppm and 1-MCP at 5% were the most effective treatments, with no significant differences between them. These treatments prevented ethylene production and action, which in turn reduced spear curvature during storage. Previous research has shown a positive relationship between ethylene production and increased leaf curvature or upward growth (Poyesh *et al.*, 2017). The interaction between postharvest treatments and storage periods was significant in both seasons.

Colour (L* value): The L* value, indicating colour brightness, decreased significantly with storage, resulting in darker spears (Table 4). Ozone gas treatments were the most effective at maintaining a higher L* value, indicating lighter spears. Ozone at 4 ppm, followed by ozone at 7 ppm, 1-MCP at 5%, and active MAP at 5% O2 + 5% CO2, produced spears with no significant differences in color. The control had the lowest L* value, indicating darker spears. These results were consistent with previous studies (Hussein, 2021; Ibrahim and Abdullah, 2018; Pretell-Vasquez *et al.*, 2020).

Exposure to gaseous ozone was found to decrease the activity of enzymes like catalase and peroxidase, which catalyze phenol oxidation, causing brown colors or darkening in plants (Glowacz and Rees, 2016). The maintenance of L* value was attributed to the reduction of ethylene production and subsequent decrease in the respiration rate. The interaction between postharvest treatments and storage periods was significant, with ozone gas treatments resulting in the lightest colour after 20 days of storage at 2°C.

Gas composition inside the packages: The gas composition inside the packages changed significantly during storage, with a decrease in O_2 and an increase in CO_2 levels (Table 5 and 6). These changes were primarily attributed to O_2 consumption and CO_2 production during respiration (Wang

et al., 2020). Postharvest treatments had distinct effects on gas composition. Ozone gas and 1-MCP treatments resulted in high O_2 levels and low CO_2, with significant differences between them. Passive MAP showed similar gas composition. In contrast, unpacked spears exhibited no changes in O_2 and CO_2 concentration during storage.

The high O_2 and low CO_2 levels within packages treated with ozone or 1-MCP were attributed to the removal or blocking of exogenous ethylene, which reduced the respiration rate and CO_2 accumulation (Wrzodak and Gajewski, 2015). The interaction between postharvest treatments and storage periods significantly influenced gas concentrations.

Table 6. Effect of 1-methylcyclopropane, ozone and Modified atmosphere packaging treatments and storage period on CO_2 (%) of asparagus spears during cold storage in 2022 and 2023 seasons

Treatment	0	4	8	12	16	20	Mean
				First season			
1-methylcyclopropane 5%	0.03 x	0.38 vw	0.85 u	1.73 s	2.37 p	3.33 n	1.45 D
Ozone 4 ppm	0.03 x	0.22 wx	0.53 v	1.30 t	1.83 rs	2.80 o	1.12 F
Ozone 7 ppm	0.03 x	0.32 w	0.75 u	1.67 s	2.17 pq	3.20 n	1.36 E
MAP (5% O_2 and 5% CO_2)	5.00 l	5.43 k	5.89 j	6.60 i	7.13 h	7.95 g	6.33 B
MAP (5% O_2 and 10% CO_2)	10.00 f	10.68 e	11.21 d	12.12 c	12.67 b	13.85 a	11.75 A
Passive MAP	0.03 x	0.40 vw	1.10 t	1.97 qr	2.93 o	3.83 m	1.71 C
Control	0.03 x	0.03 x	0.03 x	0.03 x	0.03 x	0.03 x	0.03 G
Mean	2.16 F	2.50 E	2.91 D	3.63 C	4.16 B	5.00 A	
				Second season			
1-methylcyclopropane 5%	0.03 v	0.36 tu	0.83 s	1.68 p	2.28 n	3.25 l	1.41 D
Ozone 4 ppm	0.03 v	0.21 uv	0.52 t	1.28 q	1.78 op	2.71 m	1.09 F
Ozone 7 ppm	0.03 v	0.29 u	0.73 s	1.65 p	2.12 n	3.13 l	1.33 E
MAP (5% O_2 and 5% CO_2)	0.03 v	5.41 j	5.87 i	6.57 h	7.08 g	7.87 f	5.47 B
MAP (5% O_2 and 10% CO_2)	0.03 v	10.66 e	11.18 d	12.11 c	12.63 b	13.76 a	10.06 A
Passive MAP	0.03 v	0.37 tu	1.08 r	1.91 o	2.84 m	3.70 k	1.66 C
Control	0.03 v	0.03 v	0.03 v	0.03 v	0.03 v	0.03 v	0.03 G
Mean	0.03 F	2.48 E	2.89 D	3.61 C	4.11 B	4.92 A	

Values with the same letter(s) are not significantly different at $P \leq 0.05$ level; using Tukey's multiple range test.

Table 7. Effect of 1-methylcyclopropane, ozone and modified atmosphere packaging treatments and storage period on total chlorophyll content (mg/100g fresh weight) of asparagus spears during cold storage

Treatment	0	4	8	12	16	20	Mean
				First season			
1-methylcyclopropane 5%	55.28 a	54.17 a-c	52.60 d-f	50.84 g-j	48.70 kl	46.16 n	51.29 C
Ozone 4 ppm	55.28 a	54.36 ab	53.71 b-d	52.73 c-f	51.65 f-i	50.48 h-j	53.03 A
Ozone 7 ppm	55.28 a	54.30 ab	53.42 b-e	52.17 e-g	50.25 ij	47.89 lm	52.22 B
MAP (5% O_2 and 5% CO_2)	55.28 a	53.80 b-d	51.44 f-i	49.50 jk	46.64 mn	43.76 pq	50.07 D
MAP (5% O_2 and 10% CO_2)	55.28 a	52.42 d-f	50.54 h-j	47.67 lm	44.26 op	40.97 r	48.52 F
Passive MAP	55.28 a	52.72 c-f	50.66 h-j	48.50 kl	45.51 no	42.61 q	49.21 E
Control	55.28 a	51.92 f-h	48.09 k-m	43.89 pq	39.86 r	35.68 s	45.79 G
Mean	55.28 A	53.39 B	51.50 C	49.33 D	46.70 E	43.94 F	
				Second season			
1-methylcyclopropane 5%	59.42 a	58.34 bc	56.75 de	55.01 h-j	52.84 l	50.31 no	55.44 C
Ozone 4 ppm	59.42 a	58.51 b	57.84 bc	56.88 de	55.78 f-h	54.62 j	57.18 A
Ozone 7 ppm	59.42 a	58.46 b	57.55 cd	56.32 e-g	54.38 jk	52.03 lm	56.36 B
MAP (5% O_2 and 5% CO_2)	59.42 a	57.96 bc	55.58 g-i	53.66 k	50.77 n	47.90 p	54.22 D
MAP (5% O_2 and 10% CO_2)	59.42 a	56.58 ef	54.68 j	51.71 m	48.38 p	45.10 r	52.65 F
Passive MAP	59.42 a	56.88 de	54.80 ij	52.66 l	49.64 o	46.74 q	53.36 E
Control	59.42 a	56.08 e-g	52.23 lm	48.05 p	43.99 s	39.82 t	49.93 G
Mean	59.42 A	57.55 B	55.63 C	53.47 D	50.82 E	48.07 F	

Values with the same letter(s) are not significantly different at $P \leq 0.05$ level; using Tukey's multiple range test.

Total chlorophyll content: The total chlorophyll content of asparagus spears decreased significantly during storage (Table 7). The results are consistent with previous findings (Wang *et al.*, 2020; Hussein, 2021). The breakdown of chlorophyll was related to the remobilization of chloroplast proteins, lipids, and metals during senescence (Christ and Hortensteiner, 2014). All postharvest treatments significantly preserved chlorophyll content compared to the control, with ozone gas at 4 or 7 ppm achieving the highest levels.

The reduction in chlorophyll loss was attributed to the ability of ozone and 1-MCP to reduce ethylene production, thereby lowering the respiration rate and metabolic activity. This, in turn, resulted in lower chlorophyllase activity and delayed chlorophyll degradation (Saftner *et al.*, 2003). The interaction between postharvest treatments and storage periods significantly affected chlorophyll content.

Phenylalanine Ammonia-lyase (PAL): PAL activity significantly increased in asparagus spears during the early storage period and then decreased until the end of storage (Table 8). Increased PAL activity was correlated with decreased shelf life and overall visual quality (An *et al.*, 2007). All postharvest treatments effectively reduced PAL activity compared to the control, with ozone gas at 4 or 7 ppm being the most effective in inhibiting PAL activity. The interaction between postharvest treatments and storage periods was significant.

Discoloration: Discoloration on the cut surface of asparagus spears increased significantly with prolonged storage (Table 9). The results are similar to previous findings (Gad El-Rab, 2018). All postharvest treatments reduced discoloration compared to the control, with ozone gas at 4 or 7 ppm and 1-MCP at 5% being the most effective. The reduction in discoloration was associated with the inhibition or regulation

Table 8. Effect of 1-methylcyclopropane, ozone and Modified atmosphere packaging treatments and storage period on phenylalanine ammonia-lyase (u/g. fresh weight) of asparagus spears during cold storage in 2022 and 2023 season

Treatment	0	4	8	12	16	20	Mean
				First season			
1-methylcyclopropane 5%	18.35 l	19.48 kl	23.81 hi	30.32 d	25.05 gh	21.14 jk	23.03 E
Ozone 4 ppm	18.35 l	18.67 l	21.13 jk	25.09 gh	18.90 l	15.46 m	19.60 G
Ozone 7 ppm	18.35 l	19.19 kl	22.57 ij	28.39 de	22.98 ij	20.00 kl	21.91 F
MAP (5% O_2 and 5% CO_2)	18.35 l	19.67 kl	25.01 gh	32.84 c	27.75 ef	22.94 ij	24.43 D
MAP (5% O_2 and 10% CO_2)	18.35 l	20.07 kl	26.32 fg	40.31 a	36.98 b	30.26 d	28.72 B
Passive MAP	18.35 l	19.93 kl	25.84 fg	34.73 c	29.97 d	25.02 gh	25.64 C
Control	18.35 l	20.19 kl	27.12 ef	41.99 a	38.12 b	33.14 c	29.82 A
Mean	18.35 E	19.60 D	24.54 C	33.38 A	28.54 B	24.00 C	
				Second season			
1-methylcyclopropane 5%	16.26 s	17.39 q-s	21.72 mn	28.23 g	22.96 lm	19.05 op	20.93 E
Ozone 4 ppm	16.26 s	16.58 rs	19.04 op	22.99 lm	16.80 q-s	13.36 t	17.51 G
Ozone 7 ppm	16.26 s	17.09 q-s	20.47 no	26.29 hi	20.88 n	17.90 p-r	19.82 F
MAP (5% O_2 and 5% CO_2)	16.26 s	17.58 p-s	22.91 lm	30.75 f	25.66 ij	20.85 n	22.33 D
MAP (5% O_2 and 10% CO_2)	16.26 s	17.98 p-r	24.23 j-l	38.21 b	34.35 d	27.63 gh	26.44 B
Passive MAP	16.26 s	17.84 p-r	23.75 kl	32.64 e	27.88 g	22.93 lm	23.55 C
Control	16.26 s	18.13 pq	25.03 i-k	39.90 a	36.02 c	31.04 f	27.73 A
Mean	16.26 F	17.51 E	22.45 C	31.29 A	26.36 B	21.82 D	

Values with the same letter(s) are not significantly different at $P \leq 0.05$ level; using Tukey's multiple range test.

Table 9. Effect of 1-methylcyclopropane, ozone and Modified atmosphere packaging treatments and storage period on discoloration (score) of asparagus spears during cold storage in 2022 and 2023 seasons

Treatment	0	4	8	12	16	20	Mean
				First season			
1-methylcyclopropane 5%	1.00 h	1.00 h	1.00 h	1.00 h	1.33 gh	1.67 fg	1.17 DE
Ozone 4 ppm	1.00 h	1.00 h	1.00 h	1.00 h	1.00 h	1.00 h	1.00 E
Ozone 7 ppm	1.00 h	1.00 h	1.00 h	1.00 h	1.00 h	1.33 gh	1.06 E
MAP (5% O_2 and 5% CO_2)	1.00 h	1.00 h	1.00 h	1.33 gh	1.67 fg	2.00 ef	1.33 D
MAP (5% O_2 and 10% CO_2)	1.00 h	1.00 h	1.67 fg	2.00 ef	2.67 cd	3.00 c	1.89 B
Passive MAP	1.00 h	1.00 h	1.33 gh	1.67 fg	2.00 ef	2.33 de	1.56 C
Control	1.00 h	1.67 fg	2.33 de	3.67 b	4.67 a	5.00 a	3.06 A
Mean	1.00 E	1.10 E	1.33 D	1.67 C	2.05 B	2.33 A	
				Second season			
1-methylcyclopropane 5%	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.67 de	1.11 DE
Ozone 4 ppm	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.00 E
Ozone 7 ppm	1.00 f	1.00 f	1.00 f	1.00 f	1.00 f	1.33 ef	1.06 DE
MAP (5% O_2 and 5% CO_2)	1.00 f	1.00 f	1.00 f	1.00 f	1.33 ef	2.00 cd	1.22 CD
MAP (5% O_2 and 10% CO_2)	1.00 f	1.00 f	1.33 ef	1.67 de	2.33 c	3.00 b	1.72 B
Passive MAP	1.00 f	1.00 f	1.00 f	1.33 ef	1.67 de	2.33 c	1.39 C
Control	1.00 f	1.33 ef	2.00 cd	3.33 b	4.33 a	4.67 a	2.78 A
Mean	1.00 D	1.05 D	1.19 D	1.48 C	1.81 B	2.29 A	

Values with the same letter(s) are not significantly different at $P \leq 0.05$ level; using Tukey's multiple range test.

of enzymatic activity, including phenylalanine ammonia-lyase (Wang and Fang, 2019). The high CO_2 and low O_2 concentration inside scaled packages inhibited PAL activity and physiological processes, thus maintaining visual quality and reducing colour change. The interaction between postharvest treatments and storage periods significantly influenced discoloration.

Total phenolic content: The total phenolic content of asparagus spears decreased significantly with prolonged storage (Table 10). This decrease was attributed to the oxidation of polyphenol oxidase (PPO) enzymes, which led to the formation of colored quinines (Pretell-Vasquez *et al.*, 2021). The preservation of phenolic content was most effective with ozone gas treatments at 4 or 7 ppm, followed by 1-MCP at 5%. Ozone treatments were found to modify the cell wall, increasing the extraction and release capacity of conjugated phenolic compounds (Tabakoglu and Karaca, 2018). Postharvest CO_2 enrichment stimulated antioxidant activities and phenolic content, and elevated CO_2 was a physiological response that promoted the synthesis and accumulation of phenolics.

Regarding the interaction between postharvest treatments and storage periods, spears treated with ozone gas at 4 or 7 ppm showed the best maintenance of phenolic content compared to other treatments or the untreated control after 20 days of storage in both seasons.

The treatment of asparagus spears with 4 ppm of ozone gas proved to be the most efficacious in maintaining the quality characteristics of the spears. This treatment demonstrated exceptional spear appearance, with no signs of discoloration or curvature throughout a 20-day storage period at 2°C and 90-95% relative humidity.

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Table 10. Effect of 1-methylcyclopropane, ozone and Modified atmosphere packaging treatments and storage period on total phenolic content (mg/100 g. f. w.) of asparagus spears during storage in 2022 and 2023 seasons

Treatment	0	4	8	12	16	20	Mean
				First season			
1-methylcyclopropane 5%	23.17 a	22.20 b-d	21.11 gh	19.95 jk	18.97 lm	17.95 n	20.56 C
Ozone 4 ppm	23.17 a	23.12 a	22.99 a	22.71 a-c	22.53 a-d	21.84 d-f	22.73 A
Ozone 7 ppm	23.17 a	22.90 ab	22.15 c-e	21.48 e-g	20.93 gh	19.97 j	21.77 B
MAP (5% O_2 and 5% CO_2)	23.17 a	22.14 c-e	20.68 hi	19.01 l	17.88 n	16.54 p	19.90 D
MAP (5% O_2 and 10% CO_2)	23.17 a	21.29 f-h	19.26 kl	16.97 op	15.01 q	12.98 r	18.12 F
Passive MAP	23.17 a	21.92 d-f	20.17 ij	18.28 mn	16.74 p	15.25 q	19.25 E
Control	23.17 a	20.61 h-j	17.63 no	14.87 q	11.95 s	8.93 t	16.19 G
Mean	23.17 A	22.02 B	20.57 C	19.04 D	17.71 E	16.21 F	
				Second season			
1-methylcyclopropane 5%	27.69 a	26.74 b-d	25.63 e-g	24.48 ij	23.50 kl	22.46 m	25.08 C
Ozone 4 ppm	27.69 a	27.65 a	27.50 ab	27.24 ab	27.07 a-c	26.36 c-e	27.25 A
Ozone 7 ppm	27.69 a	27.20 ab	26.67 b-d	26.00 d-f	25.46 f-h	24.49 ij	26.25 B
MAP (5% O_2 and 5% CO_2)	27.69 a	26.67 b-d	25.19 f-i	23.53 kl	22.41 m	21.05 o	24.42 D
MAP (5% O_2 and 10% CO_2)	27.69 a	25.82 e-g	23.77 jk	21.49 no	19.54 p	17.49 q	22.64 F
Passive MAP	27.69 a	26.32 c-e	24.68 hi	22.80 lm	21.27 o	19.76 p	23.75 E
Control	27.69 a	25.14 g-i	22.14 mn	19.39 p	16.48 r	13.44 s	20.71 G

References

Aday, M.S., M.B. Buyukcan, R. Temizkan and C. Caner, 2014. Role of ozone concentrations and exposure times in extending shelf life of strawberry. *Sci. & Eng.,* 36: 43-56.

Amarante, C., N.H. Banks and S. Ganesh, 2001. Relationship between character of skin cover of coated pears and permeance to water vapour and gases. *Postharvest Biol. Technol.,* 21: 291-301.

An, J., M. Zhang, Q. Lu and Z. Zhang, 2006. Effect of a pre-storage treatment with 6- benzyl aminopurine and modified atmosphere packaging storage on the respiration and quality of green asparagus spears. *J. of Fd. Eng.,* 77: 951-957.

An, J., M. Zhang and Q. Lu, 2007. Changes in some quality indexes in fresh-cut green asparagus pretreated with aqueous ozone and subsequent modified atmosphere packaging. *J. of Fd. Eng.,* 78(1): 340-344.

Anon, 1986. United States Standards for Grades of Fresh Asparagus. Code of Federal Regulations: *Agr.,*7(51): 3720-3733.

AOAC, 1990. Quality of Official Analytical Chemists, Washington DC. USA. Ardakani, M.D. and Y. Mostofi, 2019. Postharvest application of chitosan and thymus essential oil increase quality of the table grape *cv.* Shahroudi. *J. Hortic. and Posth. Res.,* 2(1): 31-42.

Benyathiar, P., B. Harte and J. Harte, 2020. Shelf life extension of fresh asparagus using modified atmosphere packaging and vacuum skin packaging in microwavable tray systems. *Packag. Technol. Sci.,* 33: 407-415.

Cantwell, M., X. Nie and G. Hong, 2009. Impact of storage conditions on grape tomato quality. *6th ISHS Postharvest Symposium,* Antalya, Turkey, 8 pp.

Cheng, G.W. and P.J. Breen, 1991. Activity of phenylalanine ammonialyase (PAL) and concentrations of anthocyanins and phenolics in developing strawberry fruit. *J. Amer. Soc. Hortic. Sci.,* 116: 865-869.

Christ, B. and S. Hortensteiner, 2014. Mechanism and significance of chlorophyll breakdown. *J. Plant Growth Regul.,* 33: 4-20.

Gad EL-Rab, N.A. 2018. Effect of some pre and postharvest treatments on yield, quality and storability of snap beans. Ph.D. Thesis, Fac. Agric., Cairo Univ., Cairo, Egypt, 252 pp.

Glowacz, M. and D. Rees, 2016. Exposure to ozone reduces postharvest quality loss in red and green chili peppers. *Fd. Chem.,* 210: 305-310.

Hua-lia, X., B. Yang, H. Razac, W. Hu-Jun, P. Lu-Meia, N. Mi-Na, C. Xiao-Yan, W. Yi and L. Yong-Cai, 2019. Detection of NEO in muskmelon fruits inoculated with *Fusarium sulphureum* and its control by postharvest ozone treatment. *Fd. Chem.,* 254: 193-200.

Hussein, N.M. 2021. Impact of some edible coating on postharvest quality of asparagus and broccoli. Ph.D. Thesis, Fac. Agric., Ain Shams Univ., Cairo, Egypt, 166 pp.

Ibrahim, H.A. and M.A.A. Abdullah, 2018. Effects of 1-methylcyclopropane on quality of tomato and sweet pepper fruits during mixed loads. *Bioscience Res.,* 15(1): 270-279.

Kader, A.A. 2002. Methods of gas mixing, sampling and analysis. In A. A. Kader (Ed.), Postharvest technology of horticultural crops (pp.145-148). Berkeley, CA: University of California and Agricultural and Natural Resources, publication 3311.

Kader, A.A., L.L. Morris and E.C. Maxie, 1973. Systems for scoring quality of harvested lettuce. *Hortic. Sci.,* 8: 408-409.

Loaiza-Velarde, J.G. and M. E. Saltveit, 2001. Heat shocks applied either before or after wounding reduce browning of lettuce leaf tissue. *J. Amer. Soc. Hortic. Sci.,* 126: 227-234.

Mangaraj, S. and T.K. Goswami, 2009. Modified atmosphere packaging of fruits and vegetables for extending shelf life- A review. *Fresh Prod.,* 3: 1-31.

Mc Guire, R.E. 1992. Reporting of objective colour measurement. *HortScience,* 27: 1254- 1255.

Mshraky, A.M. 2017. The impact of some innocuous treatments (UV, ozone, anise oil and acetic acid) on maintaining the quality attributes of "Swelling" peach fruit at cold storage. *Intl. J. Chem. Tech. Res.,* 10(2): 332-344.

Paull, R.E. and N.J. Chen, 1999. Heat treatment prevents postharvest geotropic curvature of asparagus spears (*Asparagus officinalis* L.). *Postharvest Biol. and Technol.,* 16: 37-41.

Poyesh, D.S., N. Terada, A. Sanada, H. Gemma and K. Koshio, 2017. Effect of 1- MCP on ethylene regulation and quality of apple, apricot and asparagus. *J. ISSAAS,* 23(1): 90-102.

Poyesh, D.S., N. Terada, A. Sanada, H. Gemma and K. Koshio, 2018. Effect of 1- MCP on ethylene regulation and quality of tomato *cv.* Red Ore. *Intl. Fd. Res. J.,* 25(3): 1001-1006.

Pretell, C., L. Marquez and R. Siche, 2016. Efecto del ozono gaseoso sobre las caracteristicas fisicoquímicas, microbiologicas y apariencia general de *Punica Granatum* L. wonderful fresca. *Scientia Agropecuaria,* 7(3): 173-180.

Pretell-Vasquez, C., L. Marquez-Villacorta, R. Siche and M. Hayayumi-Valdivia, 2020. Effect of ozone and storage time on the physicochemical characteristics of minimally processed green asparagus (*Asparagus officinalis* L.). *Cienc. Technol. Agropecuaria,* 21(3): 1-16.

Pretell-Vasquez, C., L. Marquez-Villacorta, R. Siche and M. Hayayumi-Valdivia, 2021. Optimization of ozone concentration and storage time in green asparagus (*Asparagus officinalis* L.) using response surface methodology. *J. Vitae.,* 28(3): 1-10.

Qiu, M., H. Jiang, G. Ren, J. Huang and X. Wang, 2013. Effect of chitosan coatings on postharvest green asparagus quality. *Carbohydrate Polymers,* 92(2): 2027-2032.

Queiroz, C., M.M. Lopes, E. Fialho and V.L. Valente-Mesquita, 2008. Polyphenol oxidase: characteristics and mechanisms of browning control. *Fd. Rev. Intl.,* 24: 361-375.

Sabir, F.K., S. Kusvuran, H.Y. Dasgan and I.T. Agar, 2012. Effects of 1-methylcyclopropene treatment on postharvest life and quality in four tomatoes cultivars. *The J. Animal & Plant Sci.,* 22(4): 1086-1091.

Saftner, R.A., J.A. Abbot and W.S. Convay, 2003. Effects of 1-methylcyclopropene and heat treatments on ripening and postharvest decay in 'Golden Delicious' apples. *J. Amer. Soc. Sci.,* 128: 120-127.

Singleton, V.L., R. Orthofer and R. M. Lamuela-Raventós, 1999. Analysis of total phenols other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. *Methods in Enzymology,* 299: 152-178.

Snedecor, G.W. and W.G. Cochran, 1980. *Statistical Methods*. 8th Ed., Iowa State Univ. Press, Ames, Iowa, USA., 476 pp.

Tabakoglu, N. and H. Karaca, 2018. Effects of ozone-enriched storage atmosphere on postharvest quality of black mulberry fruits (*Morus nigra* L.). *LWT-Food Sci. Technol.,* 92: 276-281.

Techavuthiporn, C. and P. Boonyaritthongchai, 2016. Effect of pre-storage short- term Anoxia treatment and modified atmosphere packaging on the physical and chemical changes of green asparagus. *Postharvest Biol. Technol.,* 117: 64-70.

Waller, R.A. and D.B. Duncan, 1969. A buyes rule for the symmetric multiple comparison problems. *Amer. State. Assoc. J.,* 64: 1484-1503.

Wang, J. and L. Fang, 2019. Effect of ultrasound treatment on microbial inhibition and quality maintenance of green asparagus during cold storage. *Ultrasonics Sonochemistry,* 58: 1-8.

Wang, L.X., I.L. Choi and H.M. Kang, 2020. Correlations among quality characteristics of green asparagus affected by the application methods of elevated CO_2 combined with MA packaging. *Hortic.,* 6 (103): 1-15.

Wrzodak, A. and M. Gajewski, 2015. Effect of 1-MCP treatment on storage potential of tomato fruit. *J. Hortic. Res.,* 23(2): 121-126.

Wu, L. and H. Yang, 2016. Combined application of carboxymethyl chitosan coating and brassinolide maintains the postharvest quality and shelf life of green asparagus. *J. Food Proc. Preserv.,* 40: 154-165.

Yoon, H.S., I.L. Choi, J.P. Baek and H.M. Kang, 2016. Effects of 1-MCP and MA storage treatments for long-term storage of asparagus spears. *Prot. Hortic. Plant Fact.,* 25(2): 118-122.

Zhang, J., F. Zhang, D. Li, Y. Liu, B. Liu and X. Meng, 2019. Characterization of metabolite profiles of white and green spears of *Asparagus officinalis* L. from Caoxian, North China. *Food Res. Intl.,* 128: 1-53.

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