Research Paper

Future of Food: Journal on Food, Agriculture and Society
11 (4) November 2023

Effect of Storage Temperatures and Modified Atmosphere Packaging on Sprouting and Quality Attributes of Fresh Peeled Garlic Cloves

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Data of the article

First received : 27 July 2023 | Last revision received : 08 September 2023
Accepted : 13 November 2023| Published online : 30 November 2023
DOI : 10.17170/kobra-202307218411

Keywords

Garlic; Storage Temperatures; Modified Atmosphere Packaging; Quality; Storability

This study was conducted during the 2021 and 2022 seasons to evaluate the influence of active modified atmosphere packaging (MAP) at levels of 3% O_2 + 5% CO_2, 3% O_2 + 10% CO_2, 3% O_2 + 15% CO_2, 3% O_2 + 97% N_2, and 5% N_2 + 95% O_2 compared with passive MAP as a control on sprouting and rooting delay and maintaining quality attributes of freshly peeled garlic cloves during storage at 5 and 10°C and 90 - 95% relative humidity for 20 days. The results indicated that all active MAP treatments were effective in reducing weight loss, colour changes, O_2 consumption, CO_2 production, and polyphenol oxidase activity, retarding sprouting and rooting growth, and maintaining pyruvic acid, total phenolic contents, and the overall appearance of peeled garlic cloves during storage as compared with passive MAP (control). Also, all cloves stored at 5°C were the best in all quality attributes compared to those stored at 10°C. However, peeled garlic cloves packed in active MAP at 3% O_2 + 15% CO_2 and stored at 5°C proved to be the most effective treatment in retarding sprouting growth and preserving all the quality attributes of the cloves. Furthermore, this treatment showed the excellent appearance of cloves without any rooting or discoloration after 20 days of storage at 5°C, while those stored at 10°C gave a good appearance after 16 days of storage. Cloves packed in 3% O_2 + 95% N_2 gave an excellent appearance for 16 days of storage at 5°C and gave a good appearance after 12 days of storage at 10°C. Whereas, passive MAP gave an unsalable appearance at the end of storage at 5°C and 10°C.

1. Introduction

Garlic (*Allium sativum L.*) is widely used as a therapeutic food and a flavouring agent. Owing to rapid urbanisation and more women joining the workforce, the use of ready-to-eat, minimally processed convenience foods is gaining increasing popularity. Because the peeling of garlic is a laborious and time-consuming process, the peeled garlic clove is a popular commodity among minimally processed vegetable products in the market and attracts the interest of retail food stores, restaurants, and consumers because of its convenience and suitability for modern lifestyles (Cantwell & Suslow, 2002). However, the peeling process results in broken and damaged pieces, and damage is the major factor leading to decay and quality loss during storage. Physical damage that occurs during the peeling process contributes to increased respiration rates and spoilage of minimally processed products (Ramirez-Moreno et al., 2000). Like other minimally processed vegetables, the exposed produce surface in peeled garlic cloves accelerates surface dis-

coloration, including enzymatic and non-enzymatic browning, moisture loss, microbial spoilage, and senescence, which results in short shelf life and poor quality. Other important factors contributing to the loss of quality include sprouting and rooting, which result from high humidity in plastic packaging without a modified atmosphere and as a result of storage at temperatures higher than the recommended temperature of 0 - 2 °C (Cantwell & Suslow, 2002). Therefore, it is necessary to use some techniques to reduce sprouting growth, maintain all quality attributes, and extend the shelf life of peeled garlic cloves. The major factors affecting the shelf life of peeled garlic cloves are storage temperatures and modified atmosphere packaging (Tanamati et al., 2016).

Temperature management is one of the most important tools for extending the shelf life of fruits (Lee & Kader, 2000) because it regulates the rate of all associated physiological and biochemical processes. If the storage temperature is lower or higher than the optimum temperature of the product, this will deteriorate the quality and reduce the product's storage life (Khorshidi et al., 2010).

Peeled garlic should be stored at 0-5°C to maintain quality. The storage life is expected to be 2 to 3 weeks if the cloves are stored at 5°C or below, while storage temperatures above 5°C will encourage root and shoot development and cause discoloration of the cloves in damaged areas to turn pink and brown (Kang & Lee, 1999). Furthermore, Cantwell et al. (2003a) found that for peeled garlic cloves stored at 0 and 5°C, excellent visual quality was maintained during >21 and 16 days of storage, respectively. At 10 and 15°C, acceptable quality was maintained for 12 and 8 days, respectively.

Modified atmosphere packaging (MAP) is a preservation technique used to prolong the shelf life of processed or fresh food by changing the composition of the air surrounding the food in the package. The MAP technology works by increasing CO_2 levels and decreasing O_2 levels in the package (Martinez-Romero et al., 2003). MAP may be created as a result of the commodity's own respiration (passive MAP) or by the addition and removal of gases from food packages (active MAP) to manipulate O_2 and CO_2 levels (Daş et al., 2006). Reduced O_2 and/or enriched CO_2 levels can reduce respiration and metabolic activity, prevent water loss, retard textural softening, delay browning, maintain colour, lower microbial populations, and slow down compositional changes associated with ripening, thereby resulting in an extension of shelf life and preserving the quality (Gonzalez-Aguilar et al., 2004). Moreover, the use of MAP has proved useful in maintaining fruit firmness by reducing or inhibiting the activities of enzymes responsible for degrading pectin polysaccharides (Femenia et al., 1998).

MAP (low O_2 and high CO_2) was the most effective treatment for retaining firmness, colour, total soluble solids, total antioxidant activity, total phenols, and pyruvic acid of peeled garlic throughout the storage period at 10°C (Madhav et al., 2016), reducing the colour change, and suppressing the sprouting and rooting of the garlic cloves (Kang & Lee, 1999). Furthermore, high carbon dioxide atmospheres retarded discoloration and decay, reduced sprout development in peeled garlic during storage at 5 and 10°C (Ramirez-Moreno et al., 2000), and preserved an acceptable quality of peeled garlic cloves stored at 10°C without any injuries (Attia & Atress, 2016). Also, fresh-cut red cabbage stored in MAP with 95% N_2 + 5% O_2 delayed microbial growth, decreased weight loss, and discoloration, maintained very good quality and freshness and gave a good visual appearance for 16 days of storage at 0°C (Atress et al., 2011).

A reasonable expected storage life of commercially peeled and modified-atmosphere-packaged garlic is 3-4 weeks at 0°C, 2-3 weeks at 5°C, and 1-2 weeks at 10°C (Tanamati et al., 2016). Therefore, the objective of the present study was to evaluate the effect of storage temperatures and modified atmosphere packaging on sprouting and quality attributes of fresh-peeled garlic cloves during storage at 5oC and 10oC and 90-95% relative humidity for 20 days.

2. Materials and Methods

2.1. Sample Preparation

Garlic bulbs (*Allium sativum L.*) cv. Seds 50 were harvested in the commercial maturity stage of marketing on the 18th and 23rd of May in the 2021 and 2022 seasons, respectively, and field cured on a local farm located in Beni Suef Governorate, Egypt. Garlic bulbs were transported to the laboratory of Handling of Vegetable Crops Department, Agricultural Research Centre, Giza, and manually sorted to select uniform-sized

ISSN-Internet 2197-411x OLCL 862804632

bulbs free from blemishes. They were then stored at room temperature for 4 months. The outer cloves of the garlic bulb were peeled and hand-dehulled (the peeled garlic cloves were prepared by breaking the bulbs into individual cloves and removing the husk shell manually without any machine) after breaking the dormancy, and the growth of the sprout reached 50% of full clove length. "Dormancy is a physiological phenomenon in plants, and it is a period where the activity of the plant, such as growth and development, is temporarily stopped. The garlic bulb has a dormancy period of more than 3 months, but as the time of postharvest storage is prolonged, the dormancy of the bulb is broken and sprout growth commences (Woldeyes et al., 2017)".

2.2. Modified Atmosphere Packaging (MAP)

Peeled garlic cloves were packed in polyethylene bags (30µm thickness, 10 × 15 cm size) and divided into six treatments. The six treatments were applied as follows: the bags were sealed and flushed with different gas mixtures (active MAP) at 3% O_2 + 5% CO_2, 3% O_2 + 10% CO_2, 3% O_2 + 15% CO_2, 3% O_2 + 97% N_2 and 5% N_2 + 95% O_2, and without flushing (passive MAP) as a control treatment. Each bag contains about 100 gram of cloves as an experimental unit. Thirty experimental units were prepared for each treatment; all samples were stored at 5°C and 10°C and 90 - 95 % relative humidity for 20 days (fifteen samples from each treatment for each storage temperature degree). The design of the experiment was completely randomized design with three replicates; the treatments were assigned to the experimental units completely at random. This allows every experimental unit to have an equal probability of receiving a treatment. Replication refers to the number of distinct experimental units under the same treatment. Replication, with randomization, will provide a basis for calculating the experimental error variance. The greater the number of replications, the greater the precision of the experiment and the lower the experimental error. Three samples were randomly selected from each treatment and were examined immediately after harvest and after 4, 8, 12, 16, and 20 days at 5°C and 10°C for the following properties:

2.3. Data Collection

1. The percentage of weight loss was calculated using the following equation:

$$\text{Weight loss \%} = \frac{\text{Initial weight of bag} - \text{weight of bag at sampling date}}{\text{Initial weight of bag}} \times 100$$

2. The general appearance (score) was evaluated on a scale from 9 to 1, with 9 being excellent, 7 being good, 5 being fair, 3 being poor, and 1 being unsalable; fruits rated (5 or lower) were judged unmarketable. It was recorded for wilting, surface colour discoloration, rooting and sprouting development, and any other visible deterioration, as stated by Attia & Atress (2016).

3. The sprouting ratio was estimated by cutting cloves longitudinally in half and the length of the sprout was measured with a ruler (mm) and the ratio of sprouting was reported as a fraction of the full clove length. A value of sprout length > 1.0 indicates sprout emergence Cantwell et al. (2003b).

4. Rooting (mm) was estimated by visual observation and measuring it with a ruler, as described by Dronachari et al. (2010).

5. Discoloration (score) was evaluated on a scale of 1 to 5, where 1= none, 2= slight, 3= moderate, 4= severe, and 5= extra severe, as described by Cantwell et al. (2009).

6. Colour was measured by using the Minolta CR-400 Chroma Meter (Minolta Co., Ltd., Osaka, Japan) to get readings for the Lightness (L* value) of the colour found on the outside surface of cloves. Lightness was used to express the gloss and skin colour. During the entirety of each data observation, three readings were taken from each garlic clove at different locations (McGuire, 1992).

7. Gas composition in package (%): O_2 and CO_2 concentrations in the package were measured with a Dual Trak Model 902 D gas analyser. It is an oxygen and CO_2 headspace analyser used for the measurement of residual oxygen and carbon dioxide in gas-flushed food packages. This headspace analyser contains an internal pump to draw in samples from the package and display O_2 and CO_2 concentration results by inserting the test probe through a rubber seal attached to the outside of the packaging.

8. Pyruvic acid content (mg/100g F.W.) as determined according to Schwimmer & Weston (1961).

9. Total phenolic content (mg/100g F.W.) as determined according to Singleton et al. (1999).

10. Polyphenol oxidase (PPO) activity (mg/100g F.W.) as determined according to Dogan et al. (2002).

2.4. Statistical Analysis

Statistical analysis was performed on the studied traits for each season, and pooled analysis was carried out when the errors were homogenous. The combined data across the two seasons of the study was analysed. The collected data were submitted for analysis of variance using SPSS. Mean separations were estimated by calculating LSD at the 5% level. The homogeneity of variances for the two seasons was checked by the Levene (1960) test.

3. Results

3.1. Weight loss

Data in Table 1 indicate that there was a significant increase in weight loss % with the prolongation of the storage period. All the active modified atmosphere packaging (MAP) treatments significantly reduced the weight loss % of cloves as compared to the control (passive MAP). Moreover, active MAP at 3% O_2 + 15% CO_2 was the best treatment for significantly reducing the percentage of weight loss (0.43%), followed by 3% O_2 + 95% N_2 (0.56%) and 3% O_2 + 10% CO_2 (0.65%) with no significant difference between them. While passive MAP treatment recorded the greatest percentage of weight loss (1.21%). Concerning the effect of storage temperatures, cloves stored at 5°C reduced the weight loss (0.67%) as compared to those stored at

Table 1. Effect of storage temperatures and modified atmosphere packaging on weight loss (%) of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5°C	3% O_2 + 5% CO_2	0.00	0.52	0.77	1.02	1.28	1.62	**0.87**
	3% O_2 + 10% CO_2	0.00	0.19	0.37	0.60	0.92	1.34	**0.57**
	3% O_2 + 15% CO_2	0.00	0.11	0.24	0.39	0.55	0.78	**0.35**
	3% O_2 + 97% N_2	0.00	0.24	0.54	0.83	1.13	1.47	**0.70**
	3% O_2 + 95% N_2	0.00	0.14	0.31	0.50	0.78	1.11	**0.47**
	Passive MAP	0.00	0.85	1.05	1.29	1.55	1.83	**1.09**
	Mean	**0.00**	**0.34**	**0.54**	**0.77**	**1.04**	**1.36**	**0.67**
10°C	3% O_2 + 5% CO_2	0.00	0.65	0.95	1.30	1.66	2.04	**1.10**
	3% O_2 + 10% CO_2	0.00	0.26	0.49	0.81	1.19	1.64	**0.73**
	3% O_2 + 15% CO_2	0.00	0.20	0.33	0.55	0.86	1.17	**0.52**
	3% O_2 + 97% N_2	0.00	0.34	0.70	0.98	1.40	1.89	**0.89**
	3% O_2 + 95% N_2	0.00	0.26	0.47	0.71	1.06	1.46	**0.66**
	Passive MAP	0.00	0.97	1.26	1.54	1.87	2.30	**1.32**
	Mean	**0.00**	**0.45**	**0.70**	**0.98**	**1.34**	**1.75**	**0.87**
Mean	3% O_2 + 5% CO_2	0.00	0.59	0.86	1.16	1.47	1.83	**0.98**
	3% O_2 + 10% CO_2	0.00	0.22	0.43	0.70	1.06	1.49	**0.65**
	3% O_2 + 15% CO_2	0.00	0.15	0.29	0.47	0.71	0.98	**0.43**
	3% O_2 + 97% N_2	0.00	0.29	0.62	0.91	1.26	1.68	**0.79**
	3% O_2 + 95% N_2	0.00	0.20	0.39	0.60	0.92	1.28	**0.56**
	Passive MAP	0.00	0.91	1.15	1.41	1.71	2.06	**1.21**
	Mean	**0.00**	**0.39**	**0.62**	**0.87**	**1.19**	**1.55**	
LSD at 5%	Temperature (TE)=0.05		Treatment (TR)=0.09			Storage period (S)=0.09		
	TExTR=0.13		SxTR=0.22		SxTE=0.13		TExSxTR=0.31	

*MAP: Modified Atmosphere Packaging

ISSN-Internet 2197-411x OLCL 862804632

10°C (0.87%) during storage periods with significant differences between them.

The interaction among MAP, storage temperatures, and storage periods was significant. The results show that active MAP of 3% O_2 + 15% CO_2 treatment and storage at 5°C significantly reduced the weight loss % of cloves after 20 days of storage (0.78%), followed by 3% O_2 + 95% N_2 and storage at 5°C (1.11%) and 3% O_2 + 15% CO_2 and storage at 10°C (1.17%) with no significant differences between them, while cloves packed in passive MAP or active MAP of 3% O_2 + 5% CO_2 and stored at 10°C had the highest values of weight loss (2.30 & 2.04%, respectively) with no significant differences between them.

3.2. General appearance (GA)

As shown in Table 2, there was a considerable decrease in the GA score of freshly peeled garlic cloves with increasing storage duration. However, there were significant differences among all active MAP treatments and passive MAP treatment (control) in maintaining GA during storage periods. The active MAP of 3% O_2 + 15% CO_2 was the best treatment for maintaining GA (8.61), followed by 3% O_2 + 95% N_2 treatment (8.14). On the other hand, passive MAP treatment had the lowest score in this concern (6.25). Concerning the effect of storage temperatures, peeled garlic cloves stored at 5°C recorded the highest significant score of GA (7.94) as compared to those stored at 10°C (7.21). The interaction among MAP, storage temperatures, and storage periods on GA was significant. The results reveal that garlic cloves packed in 3% O_2 + 15% CO_2 did not exhibit any changes in their appearance till

Table 2. Effect of storage temperatures and modified atmosphere packaging on general appearance (score) of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5°C	3% O_2 + 5% CO_2	9.00	9.00	9.00	7.67	6.33	5.00	**7.67**
	3% O_2 + 10% CO_2	9.00	9.00	9.00	8.67	7.00	5.00	**7.94**
	3% O_2 + 15% CO_2	9.00	9.00	9.00	9.00	9.00	8.33	**8.89**
	3% O_2 + 97% N_2	9.00	9.00	9.00	8.33	6.67	5.00	**7.83**
	3% O_2 + 95% N_2	9.00	9.00	9.00	9.00	8.33	7.00	**8.56**
	Passive MAP	9.00	9.00	7.33	6.33	5.00	4.00	**6.78**
	Mean	**9.00**	**9.00**	**8.72**	**8.17**	**7.06**	**5.72**	**7.94**
10°C	3% O_2 + 5% CO_2	9.00	9.00	7.67	6.67	5.67	3.33	**6.89**
	3% O_2 + 10% CO_2	9.00	9.00	8.67	7.33	6.33	4.33	**7.44**
	3% O_2 + 15% CO_2	9.00	9.00	9.00	9.00	7.67	6.33	**8.33**
	3% O_2 + 97% N_2	9.00	9.00	8.33	7.00	5.67	4.00	**7.17**
	3% O_2 + 95% N_2	9.00	9.00	9.00	7.33	6.33	5.67	**7.72**
	Passive MAP	9.00	8.67	6.00	5.00	3.67	2.00	**5.72**
	Mean	**9.00**	**8.94**	**8.11**	**7.06**	**5.89**	**4.28**	**7.21**
Mean	3% O_2 + 5% CO_2	9.00	9.00	8.33	7.17	6.00	4.17	**7.28**
	3% O_2 + 10% CO_2	9.00	9.00	8.83	8.00	6.67	4.67	**7.69**
	3% O_2 + 15% CO_2	9.00	9.00	9.00	9.00	8.33	7.33	**8.61**
	3% O_2 + 97% N_2	9.00	9.00	8.67	7.67	6.17	4.50	**7.50**
	3% O_2 + 95% N_2	9.00	9.00	9.00	8.17	7.33	6.33	**8.14**
	Passive MAP	9.00	8.83	6.67	5.67	4.33	3.00	**6.25**
	Mean	**9.00**	**8.97**	**8.42**	**7.61**	**6.47**	**5.00**	
LSD at 5%	Temperature (TE)=0.16		Treatment (TR)=0.29			Storage period (S)=0.29		
	TExTR=0.40		SxTR=0.70		SxTE=0.40		TExSxTR=1.00	

*MAP: Modified Atmosphere Packaging

20 days of storage at 5°C (8.33), while those stored at 10°C gave a good appearance after 16 days of storage (7.67). Cloves packed in 3% O_2 + 95% N_2 showed an excellent appearance after 16 days of storage at 5°C (8.33) and rated a good appearance after 12 days at 10°C (7.33). While passive MAP treatment gave the unsalable appearance of cloves at the end of storage at 5°C and 10°C (4.00 & 2.00, respectively).

3.3. Sprouting ratio and Rooting

Data in Tables 3&4 show that the sprouting ratio and rooting of fresh peeled garlic cloves increased with increasing storage durations. All active MAP treatments were much better at reducing sprouting and rooting compared to passive MAP (control). Furthermore, the active MAP at 3% O_2 + 15% CO_2 was the most effective treatment in controlling sprouting and rooting growth (0.71 & 0.14 mm, respectively), followed by 3% O_2 + 95% N_2 (0.79 & 0.29 mm, respectively) and 3% O_2 + 10% CO_2 (0.88 & 0.51 mm, respectively) with a significant difference between them, while the other active MAP treatments were less effective in this regard. The higher value of sprouting and rooting growth was obtained from passive MAP (1.21& 1.50 mm, respectively). Concerning the effect of storage temperatures, cloves stored at 5°C reduce sprouting and rooting (0.87 & 0.45 mm, respectively) more than those stored at 10°C (0.97 & 0.88 mm, respectively) with significant difference between them.

Table 3. Effect of storage temperatures and modified atmosphere packaging on sprouting ratio of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5°C	3% O_2 + 5% CO_2	0.50	0.66	0.82	0.98	1.21	1.46	**0.94**
	3% O_2 + 10% CO_2	0.50	0.63	0.75	0.89	0.99	1.24	**0.83**
	3% O_2 + 15% CO_2	0.50	0.56	0.61	0.70	0.80	0.91	**0.68**
	3% O_2 + 97% N_2	0.50	0.64	0.77	0.93	1.11	1.40	**0.89**
	3% O_2 + 95% N_2	0.50	0.58	0.68	0.77	0.89	0.97	**0.73**
	Passive MAP	0.50	0.73	0.98	1.24	1.51	1.79	**1.13**
	Mean	**0.50**	**0.63**	**0.77**	**0.92**	**1.09**	**1.29**	**0.87**
10°C	3% O_2 + 5% CO_2	0.50	0.69	0.89	1.08	1.37	1.70	**1.04**
	3% O_2 + 10% CO_2	0.50	0.66	0.82	0.97	1.19	1.39	**0.92**
	3% O_2 + 15% CO_2	0.50	0.57	0.65	0.75	0.87	1.11	**0.74**
	3% O_2 + 97% N_2	0.50	0.66	0.83	0.98	1.29	1.60	**0.98**
	3% O_2 + 95% N_2	0.50	0.60	0.70	0.92	1.10	1.24	**0.84**
	Passive MAP	0.50	0.81	1.13	1.45	1.78	2.13	**1.30**
	Mean	**0.50**	**0.66**	**0.84**	**1.03**	**1.27**	**1.53**	**0.97**
Mean	3% O_2 + 5% CO_2	0.50	0.67	0.86	1.03	1.29	1.58	**0.99**
	3% O_2 + 10% CO_2	0.50	0.64	0.78	0.93	1.09	1.32	**0.88**
	3% O_2 + 15% CO_2	0.50	0.56	0.63	0.72	0.84	1.01	**0.71**
	3% O_2 + 97% N_2	0.50	0.65	0.80	0.96	1.20	1.50	**0.94**
	3% O_2 + 95% N_2	0.50	0.59	0.69	0.85	1.00	1.11	**0.79**
	Passive MAP	0.50	0.77	1.05	1.35	1.65	1.96	**1.21**
	Mean	**0.50**	**0.65**	**0.80**	**0.97**	**1.18**	**1.41**	
LSD at 5%	Temperature (TE) =0.02		Treatment (TR)=0.03			Storage period (S)=0.03		
	TExTR=0.05		SxTR=0.08		SxTE=0.05		TExSxTR=0.11	

*MAP: Modified Atmosphere Packaging

ISSN-Internet 2197-411x OLCL 862804632

Table 4. Effect of storage temperatures and modified atmosphere packaging on rooting (mm) of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5°C	3% O_2 + 5% CO_2	0.00	0.00	0.00	0.00	1.67	2.50	**0.69**
	3% O_2 + 10% CO_2	0.00	0.00	0.00	0.00	0.00	1.83	**0.31**
	3% O_2 + 15% CO_2	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	3% O_2 + 97% N_2	0.00	0.00	0.00	0.00	0.83	2.17	**0.50**
	3% O_2 + 95% N_2	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	Passive MAP	0.00	0.00	0.00	1.67	2.50	3.00	**1.19**
	Mean	**0.00**	**0.00**	**0.00**	**0.28**	**0.83**	**1.58**	**0.45**
10°C	3% O_2 + 5% CO_2	0.00	0.00	0.00	0.83	2.33	3.17	**1.06**
	3% O_2 + 10% CO_2	0.00	0.00	0.00	0.00	2.00	2.33	**0.72**
	3% O_2 + 15% CO_2	0.00	0.00	0.00	0.00	0.00	1.67	**0.28**
	3% O_2 + 97% N_2	0.00	0.00	0.00	0.00	2.00	2.83	**0.81**
	3% O_2 + 95% N_2	0.00	0.00	0.00	0.00	1.50	2.00	**0.58**
	Passive MAP	0.00	0.00	1.83	2.33	2.83	3.83	**1.81**
	Mean	**0.00**	**0.00**	**0.31**	**0.53**	**1.78**	**2.64**	**0.88**
Mean	3% O_2 + 5% CO_2	0.00	0.00	0.00	0.42	2.00	2.83	**0.88**
	3% O_2 + 10% CO_2	0.00	0.00	0.00	0.00	1.00	2.08	**0.51**
	3% O_2 + 15% CO_2	0.00	0.00	0.00	0.00	0.00	0.83	**0.14**
	3% O_2 + 97% N_2	0.00	0.00	0.00	0.00	1.42	2.50	**0.65**
	3% O_2 + 95% N_2	0.00	0.00	0.00	0.00	0.75	1.00	**0.29**
	Passive MAP	0.00	0.00	0.92	2.00	2.67	3.42	**1.50**
	Mean	**0.00**	**0.00**	**0.15**	**0.40**	**1.31**	**2.11**	
LSD at 5%	Temperature (TE)=0.07		Treatment (TR)=0.11			Storage period (S)=0.11		
	TExTR=0.16	SxTR=0.28		SxTE=0.16		TExSxTR=0.39		

*MAP: Modified Atmosphere Packaging

The interaction among MAP, storage temperatures, and storage periods on sprouting and rooting was significant. After 20 days, peeled garlic cloves exposed to active MAP at 3% O_2 + 15% CO_2 or 3% O_2 + 95% N_2 and stored at 5°C had the lowest values of sprouting and did not show any rooting (0.91 & 0.00 mm) and (0.97 & 0.00 mm), respectively, with no significant difference between them, while the highest value was recorded with cloves packed in passive MAP and stored at 10°C during the same period (2.13 & 3.83 mm, respectively).

3.4. Discoloration

As shown in Table 5, there is a considerable increase in the discoloration (score) of peeled garlic cloves with the extension of the storage duration. However, all active MAP treatments reduce the incidence of discoloration when compared to passive MAP treatment. Furthermore, active MAP at 3% O_2 + 15% CO_2 was the most effective treatment in preventing discoloration in peeled garlic cloves, which showed the lowest score of discoloration (1.10), followed by 3% O_2 + 95% N_2 treatment (1.26). Whereas passive MAP treatment showed the highest score of discoloration (2.47). Significant differences in the discoloration of cloves were found between storage temperatures (5°C and 10°C). Cloves stored at 5°C gave the lowest values of discoloration (1.49), while the highest values were recorded with cloves stored at 10°C (1.89).

The interaction among MAP, storage temperatures, and storage durations was significant. Data reveal that

Table 5. Effect of storage temperatures and modified atmosphere packaging on discoloration (score) of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5°C	3% O_2 + 5% CO_2	1.00	1.00	1.00	1.33	2.50	3.50	**1.72**
	3% O_2 + 10% CO_2	1.00	1.00	1.00	1.00	1.33	2.83	**1.36**
	3% O_2 + 15% CO_2	1.00	1.00	1.00	1.00	1.00	1.00	**1.00**
	3% O_2 + 97% N_2	1.00	1.00	1.00	1.50	2.00	3.17	**1.61**
	3% O_2 + 95% N_2	1.00	1.00	1.00	1.00	1.00	1.33	**1.06**
	Passive MAP	1.00	1.00	1.50	2.17	3.33	4.17	**2.19**
	Mean	**1.00**	**1.00**	**1.08**	**1.33**	**1.86**	**2.67**	**1.49**
10°C	3% O_2 + 5% CO_2	1.00	1.00	1.50	2.00	3.50	4.17	**2.19**
	3% O_2 + 10% CO_2	1.00	1.00	1.17	1.67	2.33	3.50	**1.78**
	3% O_2 + 15% CO_2	1.00	1.00	1.00	1.00	1.00	2.17	**1.19**
	3% O_2 + 97% N_2	1.00	1.00	1.50	1.83	2.83	3.67	**1.97**
	3% O_2 + 95% N_2	1.00	1.00	1.00	1.17	2.17	2.50	**1.47**
	Passive MAP	1.00	1.33	2.17	3.17	4.00	4.83	**2.75**
	Mean	**1.00**	**1.06**	**1.39**	**1.81**	**2.64**	**3.47**	**1.89**
Mean	3% O_2 + 5% CO_2	1.00	1.00	1.25	1.67	3.00	3.83	**1.96**
	3% O_2 + 10% CO_2	1.00	1.00	1.08	1.33	1.83	3.17	**1.57**
	3% O_2 + 15% CO_2	1.00	1.00	1.00	1.00	1.00	1.58	**1.10**
	3% O_2 + 97% N_2	1.00	1.00	1.25	1.67	2.42	3.42	**1.79**
	3% O_2 + 95% N_2	1.00	1.00	1.00	1.08	1.58	1.92	**1.26**
	Passive MAP	1.00	1.17	1.83	2.67	3.67	4.50	**2.47**
	Mean	**1.00**	**1.03**	**1.24**	**1.57**	**2.25**	**3.07**	
LSD at 5%	Temperature (TE)=0.09	Treatment (TR)=0.16		Storage period (S)=0.16				
	TExTR=0.22	SxTR=0.38	SxTE=0.22	TExSxTR=0.54				

*MAP: Modified Atmosphere Packaging

cloves packed in 3% O_2 + 15% CO_2 and stored at 5°C did not show any changes in their colour till the end of the storage period (1.00), while cloves packed in 3% O_2 + 95% N_2 and stored at 5°C showed from none to a slight score of discoloration after 20 days of storage (1.33). On the other hand, cloves packed in passive MAP and stored at 10°C resulted in severe discoloration with the highest score during the same period (4.83).

3.5. Colour (L* value)

Results in Table 6 reveal that the lightness of cloves significantly decreases with an increased storage period. However, peeled garlic cloves packed in 3% O_2 + 15% CO_2 or 3% O_2 + 95% N_2 were the best treatments for decreasing the loss of L* value (76.33 & 75.78, respectively), indicating that the skin surface colour was lighter (higher L* value) during storage with no significant difference between them, followed by 3% O_2 + 10% CO_2 and 3% O_2 + 97% N_2 treatments (74.80 & 74.51, respectively) with no significant difference between them. On the other hand, 3% O_2 + 5% CO_2 treatment was less effective in this regard (73.67), while a lower L* value was detected in the cloves packed in passive MAP (69.35), which showed darker cloves (lower L* value) during storage. There was a continuous decrease in L* values at all storage temperatures. However, cloves stored at 5°C had significantly the highest L* value (77.79), while the lowest ones were

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Table 6. Effect of storage temperatures and modified atmosphere packaging on L* value of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5°C	3% O_2 + 5% CO_2	84.05	81.86	79.44	76.67	73.49	69.37	**77.48**
	3% O_2 + 10% CO_2	84.05	82.02	79.88	77.50	74.73	71.59	**78.30**
	3% O_2 + 15% CO_2	84.05	82.94	81.50	79.66	77.48	74.88	**80.08**
	3% O_2 + 97% N_2	84.05	81.97	79.70	77.13	74.28	71.19	**78.05**
	3% O_2 + 95% N_2	84.05	82.72	81.08	79.13	76.86	73.58	**79.57**
	Passive MAP	84.05	78.24	74.87	71.73	68.04	62.66	**73.26**
	Mean	**84.05**	**81.62**	**79.41**	**76.97**	**74.14**	**70.54**	77.79
10°C	3% O_2 + 5% CO_2	84.05	79.85	74.06	67.80	60.60	52.84	**69.87**
	3% O_2 + 10% CO_2	84.05	80.33	75.33	69.78	62.97	55.32	**71.30**
	3% O_2 + 15% CO_2	84.05	80.80	75.95	70.78	65.20	58.71	**72.58**
	3% O_2 + 97% N_2	84.05	79.98	74.67	69.21	62.73	55.14	**70.96**
	3% O_2 + 95% N_2	84.05	80.68	75.78	70.17	64.05	57.25	**72.00**
	Passive MAP	84.05	74.99	68.91	62.74	55.15	46.82	**65.44**
	Mean	**84.05**	**79.44**	**74.12**	**68.41**	**61.78**	**54.30**	70.36
Mean	3% O_2 + 5% CO_2	84.05	80.85	76.75	72.24	67.05	61.10	**73.67**
	3% O_2 + 10% CO_2	84.05	81.20	77.60	73.64	68.85	63.46	**74.80**
	3% O_2 + 15% CO_2	84.05	81.87	78.73	75.22	71.34	66.79	**76.33**
	3% O_2 + 97% N_2	84.05	80.98	77.18	73.17	68.49	63.17	**74.51**
	3% O_2 + 95% N_2	84.05	81.70	78.43	74.65	70.45	65.42	**75.78**
	Passive MAP	84.05	76.61	71.89	67.23	61.59	54.74	**69.35**
	Mean	**84.05**	**80.53**	**76.76**	**72.69**	**67.96**	**62.45**	
LSD at 5%	Temperature (TE)=0.39		Treatment (TR)=0.67			Storage period (S)=0.67		
	TExTR=0.95	SxTR=1.44		SxTE=0.95		TExSxTR=2.32		

*MAP: Modified Atmosphere Packaging

obtained from cloves stored at 10°C (70.36).

In general, the interactions among MAP, storage temperatures, and storage periods were significant. After 20 days of storage, cloves packed in 3% O_2 + 15% CO_2 or 3% O_2 + 95% N_2 and stored at 5°C had the highest L* value (74.88 & 73.58, respectively) with no significant difference between them, while those packed in passive MAP and stored at 10°C had the lowest ones at the same period (46.82).

3.6. Gas composition in the package

Data in Tables 7&8 show that there was a significant decrease in O_2% and an increase in CO_2% in the packages during storage periods. The consumption of O_2 and production of CO_2 in active MAP treatments were significantly lower than those of passive MAP during the storage period. However, the lowest consumption of O_2 and production of CO_2 were recorded with cloves packed in active MAP at 3% O_2 + 15% CO_2. The storage temperature significantly affects the gas composition of the bags. Moreover, the consumption of O_2 or the production of CO_2 in the samples stored at 5°C was lower than those stored at 10°C. The average gas concentrations inside the packages in active MAP at 3% O_2 + 15% CO_2 treatment and storage at 5°C after 20 days of storage were 2.14% O_2 and 19.06% CO_2, whereas in passive MAP treatment and storage at 10°C were 12.21% O_2 and 6.59% CO_2 during the same period.

Table 7. Effect of storage temperatures and modified atmosphere packaging on O_2 % of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5°C	3% O_2 + 5% CO_2	3.00	2.73	2.43	2.12	1.78	1.41	**2.24**
	3% O_2 + 10% CO_2	3.00	2.77	2.53	2.29	2.00	1.67	**2.38**
	3% O_2 + 15% CO_2	3.00	2.89	2.73	2.54	2.34	2.14	**2.61**
	3% O_2 + 97% N_2	3.00	2.76	2.51	2.26	1.96	1.61	**2.35**
	3% O_2 + 95% N_2	5.00	4.84	4.65	4.44	4.18	3.88	**4.50**
	Passive MAP	20.80	20.23	19.45	18.47	17.31	15.89	**18.69**
	Mean	**6.30**	**6.04**	**5.72**	**5.35**	**4.93**	**4.43**	**5.46**
10°C	3% O_2 + 5% CO_2	3.00	2.66	2.31	1.95	1.57	1.15	**2.11**
	3% O_2 + 10% CO_2	3.00	2.70	2.40	2.08	1.73	1.33	**2.20**
	3% O_2 + 15% CO_2	3.00	2.86	2.65	2.39	2.13	1.88	**2.48**
	3% O_2 + 97% N_2	3.00	2.71	2.39	2.05	1.71	1.30	**2.19**
	3% O_2 + 95% N_2	5.00	4.77	4.50	4.21	3.89	3.53	**4.32**
	Passive MAP	20.80	19.72	18.36	16.62	14.51	12.21	**17.04**
	Mean	**6.30**	**5.90**	**5.43**	**4.88**	**4.25**	**3.56**	**5.06**
Mean	3% O_2 + 5% CO_2	3.00	2.69	2.37	2.03	1.67	1.28	**2.17**
	3% O_2 + 10% CO_2	3.00	2.74	2.46	2.18	1.86	1.50	**2.29**
	3% O_2 + 15% CO_2	3.00	2.87	2.69	2.47	2.24	2.01	**2.55**
	3% O_2 + 97% N_2	3.00	2.74	2.45	2.15	1.83	1.45	**2.27**
	3% O_2 + 95% N_2	5.00	4.80	4.57	4.33	4.04	3.71	**4.41**
	Passive MAP	20.80	19.98	18.90	17.55	15.91	14.05	**17.86**
	Mean	**6.30**	**5.97**	**5.58**	**5.12**	**4.59**	**4.00**	
LSD at 5%	Temperature (TE)=0.05	Treatment (TR)=0.08		Storage period (S)=0.08				
	TExTR=0.11	SxTR=0.20	SxTE=0.11	TExSxTR=0.28				

*MAP: Modified Atmosphere Packaging

3.7. Pyruvic acid content

The pungency of garlic can be measured by analysing its pyruvic acid content. The data in Table 9 show that the pyruvic acid (pungency) of peeled garlic cloves decreased significantly with increasing storage duration. However, all active MAP treatments had significantly higher pyruvic acid content as compared with passive MAP (control) during the storage period. Cloves packed in active MAP at 3% O_2 + 15% CO_2 or 3% O_2 + 95% N_2 were the most effective treatments in maintaining total pyruvic acid content (139.80 & 138.50 mg/100g F.W., respectively) with no significant differences between them, followed by 3% O_2 + 10% CO_2 and 3% O_2 + 97% N_2 treatments (134.40 & 134.10 mg/100g F.W., respectively) with no significant differences between them. On the other hand, the lowest values were observed with passive MAP treatment (126.60 mg/100g F.W.). Concerning the effect of storage temperatures, cloves stored at 5°C retained more total pyruvic acid content (137.20 mg/100g F.W.) as compared with cloves stored at 10°C (131.30 mg/100g F.W.) with significant differences between them.

The interaction among MAP, storage temperatures, and storage periods was significant. After 20 days, cloves packed in 3% O_2 + 15% CO_2 or 3% O_2 + 95% N_2 and stored at 5°C maintained total pyruvic acid content (130.80 & 128.60 mg/100g F.W., respectively) with no significant differences between them, followed

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Table 8. Effect of storage temperatures and modified atmosphere packaging on CO_2 % of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5°C	3% O_2 + 5% CO_2	5.00	5.67	6.55	7.66	8.99	10.50	**7.40**
	3% O_2 + 10% CO_2	10.00	10.58	11.34	12.34	13.51	14.92	**12.12**
	3% O_2 + 15% CO_2	15.00	15.59	16.26	17.06	17.97	19.06	**16.82**
	3% O_2 + 97% N_2	0.00	0.56	1.34	2.34	3.51	4.97	**2.12**
	3% O_2 + 95% N_2	0.00	0.54	1.18	1.97	2.97	4.37	**1.84**
	Passive MAP	0.03	0.69	1.53	2.68	4.13	6.11	**2.53**
	Mean	**5.01**	**5.60**	**6.37**	**7.34**	**8.51**	**10.00**	**7.14**
10°C	3% O_2 + 5% CO_2	5.00	5.80	6.79	7.99	9.36	11.00	**7.67**
	3% O_2 + 10% CO_2	10.00	10.73	11.65	12.77	14.12	15.65	**12.49**
	3% O_2 + 15% CO_2	15.00	15.64	16.42	17.29	18.25	19.44	**17.01**
	3% O_2 + 97% N_2	0.00	0.76	1.75	2.91	4.27	5.85	**2.59**
	3% O_2 + 95% N_2	0.00	0.68	1.48	2.37	3.43	4.87	**2.14**
	Passive MAP	0.03	0.85	1.90	3.18	4.67	6.59	**2.87**
	Mean	**5.01**	**5.74**	**6.66**	**7.75**	**9.02**	**10.58**	**7.46**
Mean	3% O_2 + 5% CO_2	5.00	5.73	6.67	7.82	9.18	10.80	**7.54**
	3% O_2 + 10% CO_2	10.00	10.65	11.49	12.56	13.82	15.29	**12.30**
	3% O_2 + 15% CO_2	15.00	15.61	16.34	17.17	18.11	19.25	**16.92**
	3% O_2 + 97% N_2	0.00	0.66	1.54	2.62	3.89	5.41	**2.35**
	3% O_2 + 95% N_2	0.00	0.61	1.33	2.17	3.20	4.62	**1.99**
	Passive MAP	0.03	0.77	1.71	2.93	4.40	6.35	**2.70**
	Mean	**5.01**	**5.67**	**6.52**	**7.55**	**8.77**	**10.29**	
LSD at 5%	Temperature (TR) =0.09		Treatment (TR)=0.016			Storage period (S) =0.016		
	TExTR=0.23		SxTR=0.40		SxTE=0.23		TExSxTR=0.56	

*MAP: Modified Atmosphere Packaging

by 3% O_2 + 10% CO_2 and 3% O_2 + 97% N_2 and stored at 5°C (118.70 &117.90 mg/100g F.W., respectively) or 3% O_2 + 15% CO_2 and 3% O_2 + 95% N_2 and stored at 10°C (119.10 & 115.70 mg/100g F.W., respectively) with no significant differences between them. Cloves packed in passive MAP and stored at 10°C gave the lowest value during the same period (92.24 mg/100g F.W.).

3.8. Total phenolic content

Results in Table 10 indicate that total phenolic content decreased with the prolongation of the storage period. However, active MAP at 3% O_2 + 15% CO_2 was the most effective treatment in reducing the loss of total phenolic content during storage (28.10 mg/100g F.W.), followed by 3% O_2 + 95% N_2 treatment (27.29 mg/100g F.W.). The lowest values of total phenolic content were obtained from passive MAP (20.87 mg/100g F.W.). Concerning the effect of storage temperatures, cloves stored at 5°C gave the highest values of total phenolic content (25.25 mg/100g F.W.), while the lowest values were obtained from cloves stored at 10°C (23.03 mg/100g F.W.) with significant differences between them.

The interaction among MAP, storage temperatures, and storage periods was significant. After 20 days, cloves packed in 3% O_2 + 15% CO_2 or 3% O_2 + 95% N_2 and stored at 5°C maintained their total phenol-

Table 9. Effect of storage temperatures and modified atmosphere packaging on pyruvic acid (mg/100g F.W.) of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5°C	3% O_2 + 5% CO_2	150.10	147.40	142.50	134.90	124.70	111.70	**135.20**
	3% O_2 + 10% CO_2	150.10	147.80	143.10	136.80	128.70	118.70	**137.50**
	3% O_2 + 15% CO_2	150.10	148.80	146.50	142.70	137.60	130.80	**142.70**
	3% O_2 + 97% N_2	150.10	147.80	143.30	136.50	128.00	117.90	**137.30**
	3% O_2 + 95% N_2	150.10	148.40	145.40	141.30	136.20	128.60	**141.70**
	Passive MAP	150.10	143.80	137.20	128.10	115.50	99.54	**129.00**
	Mean	**150.10**	**147.30**	**143.00**	**136.70**	**128.50**	**117.90**	**137.20**
10°C	3% O_2 + 5% CO_2	150.10	144.40	137.10	128.50	115.90	100.50	**129.40**
	3% O_2 + 10% CO_2	150.10	144.60	137.70	129.50	119.30	106.40	**131.30**
	3% O_2 + 15% CO_2	150.10	146.10	141.20	135.70	128.50	119.10	**136.80**
	3% O_2 + 97% N_2	150.10	144.90	137.80	129.20	118.60	104.80	**130.90**
	3% O_2 + 95% N_2	150.10	145.70	140.40	134.00	125.90	115.70	**135.30**
	Passive MAP	150.10	141.50	132.00	120.90	108.00	92.24	**124.10**
	Mean	**150.10**	**144.50**	**137.70**	**129.60**	**119.40**	**106.50**	**131.30**
Mean	3% O_2 + 5% CO_2	150.10	145.90	139.80	131.70	120.30	106.10	**132.30**
	3% O_2 + 10% CO_2	150.10	146.20	140.40	133.10	124.00	112.50	**134.40**
	3% O_2 + 15% CO_2	150.10	147.40	143.90	139.20	133.10	124.90	**139.80**
	3% O_2 + 97% N_2	150.10	146.30	140.50	132.90	123.30	111.40	**134.10**
	3% O_2 + 95% N_2	150.10	147.00	142.90	137.70	131.10	122.10	**138.50**
	Passive MAP	150.10	142.60	134.60	124.50	111.70	95.89	**126.60**
	Mean	**150.10**	**145.90**	**140.30**	**133.20**	**123.90**	**112.20**	
LSD at 5%	Temperature (TE)=0.81		Treatment (TR)=1.40			Storage period (S)=1.40		
	TExTR=1.98	SxTR =3.44		SxTE=1.98		TExSxTR=4.86		

*MAP: Modified Atmosphere Packaging

ic content (21.59 & 20.34 mg/100g F.W., respectively) with no significant differences between them, followed by the same treatments stored at 10°C (19.58 & 18.28 mg/100g F.W., respectively) with no significant differences between them. Cloves packed in passive MAP and stored at 10°C gave the lowest ones during the same period (7.72 mg/100g F.W.).

3.9. Polyphenol oxidase (PPO) activity

Data in Table 11 show that the PPO activity of peeled garlic cloves increased with the prolongation of the storage period. The results show that all active MAP treatments reduced PPO activity during storage when compared to passive MAP treatment. Peeled garlic cloves packed in active MAP at 3% O_2 + 15% CO_2 were found to be the most effective treatment for reducing PPO activity (48.75 mg/100g F.W.), followed by 3% O_2 + 95% N_2 treatment (49.97 mg/100g F.W.). While passive MAP treatment had a higher increase in the activity of the PPO enzyme (62.36 mg/100g F.W.). Concerning the effect of storage temperatures, significant differences in PPO activity were found between storage temperatures (5°C and 10°C) during the storage period. Cloves stored at 5°C gave the lowest values of PPO activity (52.82 mg/100g F.W.), while the highest values were found in cloves stored at 10°C (57.15 mg/100g F.W.).

In general, the interaction among MAP, storage tem-

ISSN-Internet 2197-411x OLCL 862804632

Table 10. Effect of storage temperatures and modified atmosphere packaging on total phenolic (mg/100g F.W.) of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5°C	3% O_2 + 5% CO_2	33.48	30.03	26.25	21.69	16.67	11.02	**23.19**
	3% O_2 + 10% CO_2	33.48	31.18	27.70	23.45	18.84	13.75	**24.73**
	3% O_2 + 15% CO_2	33.48	32.71	31.13	28.90	25.66	21.59	**28.91**
	3% O_2 + 97% N_2	33.48	31.03	27.67	23.11	18.19	12.64	**24.35**
	3% O_2 + 95% N_2	33.48	32.37	30.56	28.01	24.65	20.34	**28.23**
	Passive MAP	33.48	29.53	24.89	19.96	14.86	9.58	**22.05**
	Mean	**33.48**	**31.14**	**28.03**	**24.19**	**19.81**	**14.82**	**25.25**
10°C	3% O_2 + 5% CO_2	33.48	28.37	23.62	18.47	13.03	7.61	**20.76**
	3% O_2 + 10% CO_2	33.48	28.93	24.65	20.48	15.59	10.60	**22.29**
	3% O_2 + 15% CO_2	33.48	31.14	29.26	26.89	23.40	19.58	**27.29**
	3% O_2 + 97% N_2	33.48	28.38	24.15	19.79	15.10	10.09	**21.83**
	3% O_2 + 95% N_2	33.48	30.67	28.17	25.34	22.12	18.28	**26.34**
	Passive MAP	33.48	27.17	21.70	16.53	11.51	7.72	**19.69**
	Mean	**33.48**	**29.11**	**25.26**	**21.25**	**16.79**	**12.31**	**23.03**
Mean	3% O_2 + 5% CO_2	33.48	29.20	24.93	20.08	14.85	9.31	**21.98**
	3% O_2 + 10% CO_2	33.48	30.06	26.17	21.96	17.21	12.18	**23.51**
	3% O_2 + 15% CO_2	33.48	31.92	30.19	27.89	24.53	20.59	**28.10**
	3% O_2 + 97% N_2	33.48	29.71	25.91	21.45	16.65	11.36	**23.09**
	3% O_2 + 95% N_2	33.48	31.52	29.36	26.67	23.39	19.31	**27.29**
	Passive MAP	33.48	28.35	23.29	18.25	13.19	8.65	**20.87**
	Mean	**33.48**	**30.13**	**26.64**	**22.72**	**18.30**	**13.57**	
LSD at 5%	Temperature (TE) =0.25	Treatment (TR)=0.43		Storage period (S) =0.43				
	TExTR=0.61	SxTR =1.06		SxTE=0.61		TExSxTR=1.50		

*MAP: Modified Atmosphere Packaging

peratures, and storage durations was significant. After 20 days of storage, data show that cloves packed in 3% O_2 + 15% CO_2 and stored at 5°C had the lowest values of PPO activity (49.91 mg/100g F.W.), followed by those packed in 3% O_2 + 95% N_2 and stored at 5°C or 3% O_2 + 15% CO_2 and stored at 10°C (52.65 & 57.79 mg/100g F.W., respectively) with significant differences between them. On the other hand, the highest value of PPO activity was obtained from cloves packed in passive MAP and stored at 10°C (91.81 mg/100g F.W.).

4. Discussion

Recently, consumer demand for high-quality foods requiring only a minimum amount of effort and time for preparation has increased. The peeled garlic clove is a popular commodity among minimally processed vegetable products on the market and attracts the interest of retail food stores, restaurants, and consumers because of its convenience. However, the peeling process accelerates weight loss, surface discoloration, sprouting and rooting development, microbial spoilage, and senescence, which results in quality deterioration and reduced shelf life (Cantwell & Suslow, 2002). Therefore, the aim of this study is to determine the best storage temperature and modified atmosphere packaging to slow down the sprouting and rooting, maintain quality properties, and extend the shelf life of peeled garlic cloves. The results of this study

Table 11. Effect of storage temperatures and modified atmosphere packaging on polyphenol oxidase activity (mg/100g F.W.) of peeled garlic cloves during storage in 2021 and 2022 seasons (combined analysis).

Temperature	Treatment*	Storage period (day)						
		0	4	8	12	16	20	Mean
5°C	3% O_2 + 5% CO_2	44.71	47.32	50.98	56.94	65.83	77.21	**57.17**
	3% O_2 + 10% CO_2	44.71	46.22	48.30	51.60	57.20	64.28	**52.05**
	3% O_2 + 15% CO_2	44.71	45.36	46.10	46.97	48.23	49.91	**46.88**
	3% O_2 + 97% N_2	44.71	46.40	48.46	51.93	58.05	66.43	**52.66**
	3% O_2 + 95% N_2	44.71	45.61	46.77	48.33	50.25	52.65	**48.05**
	Passive MAP	44.71	48.17	52.56	59.74	70.00	85.32	**60.08**
	Mean	**44.71**	**46.51**	**48.86**	**52.58**	**58.26**	**65.97**	**52.82**
10°C	3% O_2 + 5% CO_2	44.71	49.67	55.72	62.98	71.85	83.24	**61.36**
	3% O_2 + 10% CO_2	44.71	48.56	52.89	57.68	64.14	72.08	**56.67**
	3% O_2 + 15% CO_2	44.71	46.71	48.88	51.35	54.29	57.79	**50.62**
	3% O_2 + 97% N_2	44.71	48.90	53.67	59.11	65.74	74.32	**57.74**
	3% O_2 + 95% N_2	44.71	46.89	49.57	52.78	56.52	60.91	**51.90**
	Passive MAP	44.71	50.58	57.35	66.20	77.13	91.81	**64.63**
	Mean	**44.71**	**48.55**	**53.01**	**58.35**	**64.94**	**73.36**	**57.15**
Mean	3% O_2 + 5% CO_2	44.71	48.49	53.35	59.96	68.84	80.23	**59.26**
	3% O_2 + 10% CO_2	44.71	47.39	50.59	54.64	60.67	68.18	**54.36**
	3% O_2 + 15% CO_2	44.71	46.04	47.49	49.16	51.26	53.85	**48.75**
	3% O_2 + 97% N_2	44.71	47.65	51.06	55.52	61.89	70.38	**55.20**
	3% O_2 + 95% N_2	44.71	46.25	48.17	50.55	53.38	56.78	**49.97**
	Passive MAP	44.71	49.37	54.96	62.97	73.57	88.57	**62.36**
	Mean	**44.71**	**47.53**	**50.94**	**55.47**	**61.60**	**69.66**	
LSD at 5%	Temperature (TE)=0.45		Treatment (TR)=0.78			Storage period(S)=0.78		
	TExTR=1.10		SxTR =1.91		SxTE=1.10		TExSxTR=2.70	

*MAP: Modified Atmosphere Packaging

revealed that all active MAP treatments significantly enhanced the storability and maintained all quality properties of cloves compared to the passive MAP (control treatment). Also, all cloves stored at 5°C were the best in all quality attributes compared to those stored at 10°C. Furthermore, peeled garlic cloves exposed to active MAP at 3% O_2 + 15% CO_2 and storage at 5°C was the best treatment for reducing weight loss, sprouting, and polyphenol oxidase activity, modifying the atmosphere inside the package, maintaining pyruvic acid and total phenolic contents, and giving the excellent appearance of cloves without any rooting or discoloration for 20 days of storage, while those stored at 10°C gave a good appearance after 16 days of storage, followed by cloves packed in 3% O_2 + 95% N_2, which gave an excellent appearance for 16 days of storage at 5°C and gave a good appearance after 12 days of storage at 10°C. Whereas passive MAP gave an unsalable appearance at the end of storage at 5°C and 10°C. These results were similar to those confirmed by previous studies (Attia & Atress, 2016, Madhav et al., 2016 and Tanamati et al., 2016).

4.1. Weight loss

The rate of weight loss in peeled garlic cloves increased with prolonged storage, and these results are consistent with Attia & Atress (2016). This may be due to moisture loss through transpiration and respiration, as well as other senescence factors associated

ISSN-Internet 2197-411x OLCL 862804632

with metabolic activities during storage (Madhav et al., 2016). However, all active modified atmosphere packaging (MAP) treatments and storage at 5°C significantly reduced the weight loss of cloves compared to the passive MAP treatment (control) and storage at 10°C; these results are consistent with Madhav et al. (2016) and Tanamati et al. (2016). This may be due to the active MAP reducing the respiration rate (Sethi et al., 2014), which provides a decrease in metabolic activities, transpiration, and suppression of the enzyme activities of the product during storage (Rojas-Graü et al., 2009). Furthermore, when moisture is trapped around the product, the relative humidity increases, and the water vapour pressure deficit and transpiration decrease, reducing the weight loss during storage (Gorrepati & Bhogat 2018). Also, the slowdown of physiological processes such as respiration and transpiration that occur during storage at low temperatures (Kays, 1991). In general, the higher the storage temperature, the greater the vapour pressure deficit and the greater the weight loss of fruits (Ibrahim et al., 2018).

4.2. General appearance

The visual appearance of fresh produce is one of the most important quality factors for marketing and is affected by the prolonged storage period. According to the findings in this study, there was a considerable decrease in the general appearance (GA) score of freshly peeled garlic cloves with increasing storage duration. These results were similar to those reported by Tanamati et al. (2016), and this might be due to wilting, surface discoloration, decay, and rooting and sprouting development (Attia & Atress, 2016). However, the active MAP of 3% O_2 + 15% CO_2 and storage at 5°C was the best treatment for maintaining GA. On the other hand, passive MAP treatment and storage at 10°C had the lowest score in this concern; these results are consistent with Tanamati et al. (2016). Active MAP (high CO_2) enables significant improvements in shelf life by reducing physiological changes, respiration rate, transpiration, oxidative deterioration, and colour and pigment changes in peeled garlic cloves (Madhav et al., 2016), reducing microbial growth, and delaying softening (Singh et al., 2019). All these effects can help extend the storage time and maintain the quality of peeled garlic cloves (Madhav et al., 2016).

Also, storage at low temperatures leads to a slowdown of transpiration and respiration rates, thus reducing the speed of quality deterioration and maintaining overall quality (Chen et al., 2019).

Cantwell et al. (2003a) indicated that although a lower temperature is important to maintain the quality of peeled garlic, modified atmospheres containing CO_2 are also essential. Thus, controlling storage temperature and gas composition in the package are important methods to control respiration rate and water loss to prolong the postharvest life of garlic cloves (Chen et al., 2019). Furthermore, Cantwell et al. (2003a) showed that fresh peeled garlic exposed to MAP at CO_2 (5-15%) and O_2 (1-3%) was effective in retarding discoloration and decay during storage at 5 and 10°C for 3 weeks.

4.3. Sprouting ratio and rooting

Our findings demonstrated that the sprouting ratio and rooting of freshly peeled garlic cloves increased with increasing storage durations. These results are similar to those of Tanamati et al. (2016). Mechanical injuries in minimally processed garlic accelerate the respiration rate and deterioration rate of cloves by disrupting membranes and increasing enzymatic activity, which causes undesirable reactions. This may cause sprouting and rooting growth, which can reduce the shelf life and the marketing quality of peeled garlic cloves (Dronachari et al., 2010). However, all active MAP treatments and storage at 5°C were much better at reducing sprouting and rooting compared to passive MAP and storage at 10°C. Furthermore, the active MAP at 3% O_2 + 15% CO_2 and storage at 5°C was the most effective treatment in controlling sprouting and rooting growth. These results are consistent with Tanamati et al. (2016), who showed that lower sprouting and rooting of garlic cloves were observed with lower O_2 and higher CO_2 concentrations inside the packages, as the low oxygen content effectively inhibits its respiration rates and mechanical injuries in minimally processed garlic. Growth phenomena such as sprouting and rooting development of peeled garlic cloves are inhibited by low O_2 and/or high CO_2 (Kang & Lee, 1999), and this may be attributed to an active MAP reducing respiratory rate, thus limiting the energy supply for growth-related events; in addition, it can inhibit some enzymatic steps in the growth process

(Kader, 1986). Additionally, low temperature is one of the factors that primarily controls the emergence of the sprout (Dufoo-Hurtado et al., 2015), due to the non-activation of γ-glutamyl peptidase in garlic during storage at low temperatures (Ichikawa et al., 2006). Therefore, as the storage temperatures decreased, the sprouting and rooting decreased.

4.4. Discoloration

As indicated in the current study, the discoloration of peeled garlic cloves significantly increased with the extension of the storage duration; these results were similar to those of Tanamati et al. (2016). This may be due to the oxidation of phenolic compounds to o-quinones, a reaction catalysed by the polyphenol oxidase (PPO) enzyme. Quinones polymerize into a dark brown polymer, causing browning of the tissue (Singh et al., 2019). However, all active MAP treatments and storage at 5°C reduce the incidence of discoloration when compared to passive MAP treatment and storage at 10°C. These results are similar to those reported by Tanamati et al. (2016) and Singh et al. (2019).

This could be because of low oxygen concentrations around the clove tissues, which slow down browning reactions by reducing enzyme activity (Madhav et al., 2016). The decrease in discoloration during storage at a low temperature may be due to the temperature affecting the metabolic activity of the product and thus reaching the required rate of modified atmosphere (Kader, 1986) and a lower oxygen content in the package, which delays enzymatic browning and reduces the discoloration of the product (Singh et al., 2019). Also, storage temperatures above 5°C will result in pink and brown discoloration on the damaged areas (Kang & Lee, 1999).

4.5. Colour (L* value)

The lightness (L* value) of peeled garlic cloves was affected by the advancement of the storage period; these results are consistent with Tanamati et al. (2016). The surface colour of the peeled garlic cloves was found to be white and changed towards a lighter, redder, or more yellow colour with the prolongation of the storage period (Kang & Lee, 1999). L* value changes generally corresponded to visual appearance quality scores (Tanamati et al., 2016). From our findings, active MAP treatments and storage at 5°C were the best treatments for maintaining the L* value compared with passive MAP treatment and storage at 10°C. These results are in agreement with Tanamati et al. (2016); this may be due to the fact that active MAP reduces enzyme activity, metabolic activity, moisture loss, colour loss, browning of the flesh, and the rate of degradation of organic acids and pigments in fruits and vegetables (Alam & Goyal, 2006). The faster increase in the yellow and reddish colour of peeled garlic cloves in the control package is caused by too much oxygen, which results in enzymatic browning (Singh et al., 2019).

Additionally, the enzyme activity decreases due to the lower storage temperature (Banda et al., 2015). The low storage temperature and high CO_2 concentration inside the package reduce metabolic activity and the rate of organic acid degradation, resulting in the evolution of physicochemical and quality properties such as colour (Alam & Goyal, 2006).

4.6. Gas composition in the package

Garlic cloves are still alive and continue to respire after harvest (Madhav et al., 2016). Studying the gas changes inside the package is extremely crucial in order to achieve the proper gas composition in the packages for all treatments used. The results of this study showed that there was a significant decrease in O_2 and an increase in CO_2 in the packages during storage periods. These results are consistent with Tanamati et al. (2016) and may be due to the consumption of O_2 and the production of CO_2 by cloves during the respiration process (Madhav et al., 2016). However, the consumption of O_2 and production of CO_2 in active MAP treatments and storage at 5°C were significantly lower than those in passive MAP treatment and storage at 10 °C during the storage period. Furthermore, the lowest consumption of O_2 and production of CO_2 were recorded with cloves packed in active MAP at 3% O_2 + 15% CO_2 and stored at 5°C. These results are consistent with Tanamati et al. (2016) and Chen et al. (2019), who showed that the respiration rates of fresh-cut garlic may be reduced by reducing O_2 concentration and increasing CO_2 concentration; this is the premise for the mechanism of MAP. This was also confirmed by the variations in O_2 and CO_2 concentrations over the storage period compared to the initial

ISSN-Internet 2197-411x OLCL 862804632

concentrations of O_2 and CO_2 on day 0. These variations could be attributed to the respiration of garlic cloves, which also affects their metabolism (Singh et al., 2019; Chen et al., 2019). In addition, storage temperature had a clear impact on respiration rates; high temperatures accelerated the respiration rates of fresh-cut garlic. The values of the O_2 consumption and the CO_2 production of fresh-cut garlic stored at the same gas concentration increased by 2.5-3.5 times as the temperature increased from 5 to 20°C (Chen et al., 2019).

4.7. Pyruvic acid content

The pyruvic acid (pungency) of peeled garlic cloves decreased significantly with increasing storage duration; these results are consistent with Madhav et al. (2016), and this may be attributed to the hydrolysis of polysaccharides and non-reducing sugars, where acid is utilised for converting them to hexose sugars, and the degradation of pungency constituents, as well as cell disruption caused by volatilization and leaching of substances (Berno et al., 2014). All active MAP treatments and storage at 5°C had significantly higher pyruvic acid content as compared with passive MAP (control) and storage at 10°C during the storage period. These results are consistent with Tanamati et al. (2016) and Gorrepati & Bhagat (2018). This may be due to MAP with a low O_2 concentration, which could substantially reduce the physiological loss in weight and respiration rate, thus maintaining the pyruvic acid content of garlic (Medhav et al., 2016). Also, Singh et al. (2019) found that storage at a low temperature decreased the respiration rate and weight loss with little change in the cell structure of peeled garlic cloves.

4.8. Total phenolic content

The reduction in phenolic content in peeled garlic cloves with the prolongation of the storage period is most likely due to the PPO enzyme, which oxidises phenolic compounds in the presence of oxygen and gives the coloured quinones, which explains the parallel consumption of phenols with the development of darkening throughout the storage period (Queiroz et al., 2008). Cloves packed in active MAP treatments and stored at 5°C maintained their total phenolic content compared with those packed in passive MAP treatment and stored at 10°C. Similar results were obtained by Medhav et al. (2016), who showed that garlic stored at low O_2 concentrations maintained a higher total phenolic content because of the retardation of oxidation processes. Modified atmospheric packaging with low O_2 and high CO_2 was the most effective for retaining total antioxidant activity and total phenols throughout the storage period (Sethi et al., 2014), and modified atmospheres had a positive effect on phenolic-related quality since high CO_2 treatment is a type of abiotic stress that promotes the synthesis and accumulation of phenols as a physiological response (Tomás-Barberán & Espín, 2001). Also, high CO_2 may allow for the removal of free radicals, which are associated with an increase in antioxidant capacity (Wang et al., 2003). Additionally, this is possibly due to the effects of low temperatures on enzyme activity (He & Luo, 2007).

4.9. Polyphenol oxidase activity

The polyphenol oxidase (PPO) activity of peeled garlic cloves increased with the prolongation of the storage period. These results are consistent with Liu et al. (2021), and this may be attributed to mechanical damage from the peeling process, which led to the intracellular phenols of garlic being released and contacting polyphenol oxidase, thus increasing PPO activity. According to our findings, all active MAP treatments and storage at 5°C reduced PPO activity when compared to passive MAP treatment and storage at 10°C. Active MAP reduces enzyme activity due to a decrease in O_2 and an increase in CO_2 concentration in the headspace surrounding the garlic cloves (Madhav et al., 2016), and low temperatures reduce enzyme activity (He & Luo, 2007).

5. Conclusion

From the previous results, it could be concluded that peeled garlic cloves packed in active MAP at 3% O_2 + 15% CO_2 and stored at 5°C was the most effective treatment for retarded sprouting growth, maintained all quality attributes, and gave cloves an excellent appearance for 20 days of storage without any rooting or discoloration.

Conflict of Interest

The authors declare that they have no conflicts of in-

terest. Furthermore, the funders had no involvement in the study's design, data collection, analysis, or interpretation, manuscript preparation, or decision to publish the results.

Acknowledgement

The authors appreciate the project "Developing the export crops-extending the shelf life of fruit and reducing losses" for its assistance in supplying tools and materials used in the study.

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ISSN-Internet 2197-411x OLCL 862804632