Impact of Smart Packaging and Modified Atmosphere Packed Treatments to Keep the Quality Characteristics and Improve the Storability of Green Garlic During Cold Storage

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ABSTRACT

This investigation was carried out on green garlic cv. Balady, which is appropriate for exporting at immature stages during the seasons of 2024 and 2025. The purpose of this investigation was to study the effect of smart packaging treatments (Smart-film: Life-Span packaging, Lifepack®, and smart packaging modified) and modified atmosphere package (MAP) (active MAP at 3%O2+5%CO2 and passive MAP), as well as unpacking as a control. To maintain the quality and storability of green garlic for 20 days of cold storage at 0°C and 90-95% relative humidity. The results showed that all packaging material treatments outperformed the unpacked control regarding preserving green garlic quality and extending its storage time. Furthermore, active MAP at 3%O_2+5%CO_2 gave the best treatment, which reduced weight loss, maintaining a significantly higher L* value, pyruvic acid and titratable acidity (TA) content. Additionally, it maintained an excellent appearance for twenty days of storage without any exterior leaf development or discoloration, whereas the smart packaging modified gave a good appearance during the same period.

Keywords: Green garlic – Smart packaging – Sprouting – Discoloration – Active or passive MAP.

INTRODUCTION

Garlic (*Allium sativum* L.) belongs to the Alliaceae family. Harvesting of the green garlic at an early bulb stage when is not completely formed and is known as 'fresh garlic' (Akan et al., 2019). which is immature (green) (head diameter >4 cm, no punctuation markings on the exterior surface of the head, and neck length 12-14 cm) to be exported (Anonymous, 2019). Recently, consumers have become increasingly interested in fresh, convenient, and healthy foods that are ready to cook (Memon et al., 2018). Freshly cut fruits undergo minimal processing to keep the tissues alive and their surfaces free from pathogen growth, a process that is most important for maintaining the quality and market value of the product (Fan et al., 2003).

Green garlic is highly perishable and requires no processing before it is ready for consumption. It presents an unusual problem when processed simply because it consists of roots and stems. The head consists of leaves with a white coating and green tissue on top. The cut surfaces often show discoloration, dryness, and sometimes rot. Deformities, such as the growth or expansion of the white inner leaf bases of the head, may also occur, leading to rapid loss of quality during marketing (Ahvenainen, 1996 and Tanamati et al., 2016).

Therefore, it is necessary to use some new methods, including smart packaging (Zainuri et al., 2018) and modified atmosphere packaging (Madhav et al., 2016), are required to be used to preserve the quality and shelf life of green garlic. Smart packaging can extend the shelf life of fruits after harvest. Smart packaging technologies offer functions including gas control and antibacterial activity, as well as regulating humidity within the bag. These functions enable the packaging to automatically adjust the internal climate to the fruit's needs, inhibiting the growth of bacteria and mold, prolonging the overall freshness of the fruit, and preserving its nutritional value for as long as possible. Smart packaging integrates advanced information and sensor technologies and helps prolong fruit freshness, reduce waste and spoilage, and improve product quality and food safety by enabling real-time monitoring and control of environmental variables such as temperature, humidity, carbon dioxide and oxygen concentrations, something not possible with conventional packaging (Zainuri et al., 2018). In addition to protecting the outer layers of fruits and vegetables, this technology also improves the fruit's resistance to transportation and storage throughout the supply chain. El-Sayed et al. (2019) showed that using smart film (LifeSpan sheet lining) to wrap green garlic decreased weight loss, retained excellent visual quality throughout cold storage, as well as higher total sugar and total pungency. Smart packaging has the potential to extend product shelf life, improve product quality, and maintain freshness. Active packaging involves incorporating gas-absorbing agents and various release agents into the packaging material. This allows the product to interact with the product or its surroundings. In this way, carbon dioxide, oxygen, and relative humidity levels can be controlled, providing the best possible conditions for storing fresh-cut vegetables and fruit. On the other hand, it has the ability to regulate various factors around the fruit, preventing feeding processes, microbial growth, and extending shelf life. Unlike traditional passive packaging, active packaging not only provides protection but also regulates the internal atmosphere of the package (e.g., oxygen, humidity, carbon dioxide) or interacts with food through specific substances or technologies, thereby extending the freshness, maintaining the quality (Du et al., 2025).

Conventional modified atmosphere packaging (MAP) for fresh produce alters the atmospheric oxygen and carbon dioxide concentrations within a package encased in a diverse polymer film. Furthermore, ethylene production, respiration rates, and the growth of decomposers can be reduced through optimized gas atmospheres. Deterioration of fresh produce can also be prevented by enzymatic, chemical, and microbiological processes (Madhav et al., 2016).

The best treatment for preserving color, total soluble solids, minimizing color change, and inhibiting garlic sprouting growth was MAP (low O_2 and high CO_2) (Kang and Lee, 1999). Additionally, during storage, elevated carbon dioxide atmospheres decreased sprout formation and delayed discolouration and deterioration in fresh garlic (Ramirez-Moreno et al., 2000). Additionally, the best method for keeping the color and pyruvic acid of garlic during storage was low O_2 and high CO_2 (Madhav et al., 2016). Additionally, green garlic's quality has been preserved, and its shelf life has been increased during storage due to changed conditions packing (Hong et al., 2000).

In response to industry demand, this study examined how smart packaging and modified atmosphere packaging (MAP) affected the quality of green garlic throughout a 20-day storage period.

MATERIALS AND METHODS

Green Garlic (*Allium sativum* L.) cv. “Balady” which a favorite for exporting at immature stages. produced under usual cultivation practices in a private farm at Abu Rewash District, Giza Governorate, Egypt. Plants were harvested when bulb diameter exceeded 5-8 mm on the 19th and 23rd of February during the 2024 and 2025 seasons respectively. Plants were transferred directly to the postharvest laboratory, Handling Research Department, Giza Governorate. Defect free plants were trimmed (Roots cut off, no punctuation marks on the outer surface of the head and cut of the garlic with a neck length of 10-12 cm by a sharp knife), only healthy bulbs (uniform in size, weight and color) and free from any visible defects were selected. The experiment included six treatments as follows: Three Smart-film: Life-Span packaging, Lifepack® and smart packaging modified and active and passive Modified Atmosphere Packaging (MAP) besides the unpacked as control.

1.Life-Span packaging: Package material (polyolefin materials) are blends of low-density polyethylene, liner low density polyethylene and polypropylene together with minor amounts of plastic additives. Life-Span sheet technology can manipulate perm selectivity, which is the selective permeation of sheet materials to various gases. Through coating, micro perforation, or polymer blending, perm selectivity can be manipulated to modify the atmospheric concentration of gaseous compounds inside a package, relative to the oxidation or respiration kinetics of plant material and complies with the requirements of European Commission (EC) Regulation No. 10/2011, also classified for direct contact with food under either the European union (EU), and the United States of America (USA), Food and Drug Administration (FDA) The materials used to manufacture the Life-Span product are sourced from Australia and the USA.

1.Life-Pack: polyamide and Antifog. LifePack sheet technology can manipulate perm selectivity, which is the selective permeation of sheet materials to various gases. Through coating, micro perforation, or polymer blending, perm selectivity can be manipulated to modify the atmospheric concentration of gaseous compounds inside a package, relative to the oxidation or respiration kinetics of plant material and complies with food contact EC regulation No. 10/2011, imported from (Chantler Packaging, North America, Canada),

3.Smart film low density polyethylene (LDPE) bags, 18 µm in thickness and add slice gala and anti-fundi produced by Prime Egypt Company.

4.Active MAP polyethylene bags 30×15 cm in size, 20 µm thickness and flushed with a gas mixture at (3%O_2+5%CO_2).

5.Passive MAP Polyethylene: bags 30×15 cm in size, 20 µm thickness.

6.Unpacked (Control).

Green garlic was packed in the previous packaging materials each bag contains about 1000 grams of green garlic as an experimental unit (EU). Twelve (EU) were prepared for each treatment, each three replicates of treatment placed inside a carton box (35×22×7 cm), each treatment placed inside four carton boxes. All samples were arranged in complete randomized design in three replicates and stored at 0°C and 95% relative humidity (RH) for 20 days and samples were taken every 5 days from the initial time of storage till 20 days. The following quality measurements were recorded:

Weight loss: This was measured using the following equation: $[(W_a-W_b)/W_a] \times 100$. Where: W_a= Initial fruit weight, W_b = fruit weight at the sampling period

General appearance (score): The appearance was evaluated using a scale from (1 to 9) where 9 = excellent, 7 = good, 5 = fair and 3= poor, heads rating (5) or below was considered unmarketable. The general appearance assessment includes symptoms of deterioration. It was recorded for wilting, surface colour discoloration, rooting and sprouting development, and any other visible deterioration, as stated by Attia and Atress (2016).

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).

The leaf internal growth 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. (2003).**

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 garlic. Lightness was used to express the gloss and skin colour. During the entirety of each data observation, three readings were taken from garlic at different locations (McGuire, 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 best probe through a rubber seal attached to the outside of the packaging.

Titratable acidity (TA): was determined as percentage of citric acid, according to A.O.A.C. (1990).

Total pungency (µ mol pyruvic acid/100 gm fresh weight): Total pungency determined by measuring of pyruvate concentration according to the method of described by **Schwimmer and Weston (1961),** and Wall and Corgan (1992). The total pungency was calculated and expressed as µ mol pyruvic acid/ 100 gm fresh weight. Measurement was taken in the initial time, 10 days and 20 days of storage.

Statistical analysis: Experiments were performed in a completely randomized factorial design with three replicates. All data were subjected to statistical analysis as described by Snedecor and Cochran (1989). The method of Duncan's multiple range tests was applied for the comparison between means.

RESULTS AND DISCUSSION

1.Weight loss percentage:

Based on the data in **Table (1),** weight loss percentage gradually increased in all treatments as the storage period was extended. These findings are in line with Attia and Atress (2016) and could be caused by senescence factors caused by metabolic activities during storage (Madhav et al., 2016) as well as moisture loss through transpiration and respiration. During the storage period there were statistically significant differences between the packaging materials and the unpacked (control) materials. The garlic that was unpacked (control) lost the highest percentage of weight, but the garlic that placed in all types of packaging exhibited a significantly lower percentage of weight loss. With significant differences between them. Similar positive effects of MAP in green garlic have been reported by Akan et al. (2019).

The highest weight loss in the control (untreated) could be attributed to the garlic surface being more exposed to the open atmosphere, resulting in a higher rate of transpiration and respiration, which leads to higher weight loss **(**Mahajan and Singh, 2014). Meanwhile, MAP has proven to be an effective method for decreasing water loss during storage (Porat et al., 2009). Furthermore, MAP of fresh fruit restricts water vapour diffusion, resulting in increased water vapour pressure and relative humidity within the package.

In addition, MAP reduced the respiration rate (Sethi et al., 2014), leading to a decrease in metabolic activities, transpiration, and suppression of the product's enzyme activity during storage (Rojas-Graü et al., 2009). Moreover, when moisture is contained around a product, relative humidity increases but water vapour pressure deficit and transpiration reduce, reducing weight loss during storage. It may be believed that the packaging materials provided a microclimate with high relative humidity, low O_2 levels, and high CO_2. Each of these variables contributes to reduced respiration and transpiration rates, which affects weight loss **(**Gorrepati and Bhogat, 2018).

Concerning the interaction, there was a significant difference in storage period and packaging materials. According to the findings, active MAP at 3%O_2+5%CO_2 treatment had the lowest weight loss value, followed by smart packaging modified with no significant differences between them, and unpacked (control) had the highest weight loss value. These findings were true for both seasons after 20 days of storage.

2. General appearance:

General appearance (GA) has an impact on consumers' preference for green garlic. GA was evaluated based on surface discoloration, inner leaf extension 'telescoping' wilting, decay, and rooting and sprouting development (Attia and Atress, 2016) and is affected by the prolonged storage period. Data in **Table (2)** indicates according to the findings in this study, there was a considerable decrease in the GA score of green garlic with increasing storage duration. These results were like those reported by Tanamati et al. (2016). The highest average GA values were determined as 8.87 and 8.27 (average of the two seasons) for active MAP at 3%O_2+5%CO_2 and smart packaging modified, respectively with significant differences between them. On the other hand, the control treatment had the lowest score in this concern. These results are consistent with Tanamati et al. (2016). MAP caused higher consumer preference in terms of color and inner leaf extension. Our results have been supported by previous data on green garlic (Akan et al., 2019). Also, 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 green garlic (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 green garlic (Madhav et al., 2016). The interaction between packaging material and storage periods on GA was significant. The results reveal that green garlic storage in active MAP at 3%O_2+5%CO_2 gave an excellent appearance which did not exhibit any changes in their appearance till 20 days of storage at 0°C, while smart packaging modified treatment gave an excellent appearance after 15 days of storage and rated a good appearance after 20 days. Caleb et al. (2013) who noted that the fruit's visual appearance was highly maintained in MAP and individual shrink wrap packages during the whole storage period.

Table (1). Effect of smart packaging and MAP on weight loss percentage of green garlic during cold storage at 0°C and RH 90-95% during 2024 and 2025 seasons

Treatments	Storage periods (days)					
	0	5	10	15	20	Mean
	2024 season					
Passive MAP	0.00K	0.59E-K	0.74E-I	1.06E	1.19E	**0.72 B**
Active MAP at (3%+5%)	0.00K	0.11JK	0.18H-K	0.25G-K	0.33G-K	**0.17 C**
Smart packaging modified	0.00K	0.16I-K	0.18H-K	0.28G-K	0.40F-K	**0.20 C**
Smart packaging (Life-pack)	0.00K	0.63E-J	0.77E-H	0.74E-I	0.79E-G	**0.59 B**
Smart packaging (Life-span)	0.00K	0.62E-J	0.95EF	0.73E-I	0.80E-G	**0.62 B**
Unpacked (Control)	0.00K	4.10D	5.89C	8.02B	9.71A	**5.54 A**
Mean	**0.00 E**	**1.03 D**	**1.45 C**	**1.85 B**	**2.20 A**	
	2025 season					
Passive MAP	0.00J	0.68E-I	0.83E-H	1.15E	1.28E	**0.79 B**
Active MAP at (3%+5%)	0.00J	0.16IJ	0.19IJ	0.26H-J	0.34G-J	**0.19 C**
Smart packaging modified	0.00J	0.17IJ	0.21IJ	0.34G-J	0.44F-J	**0.23 C**
Smart packaging (Life-pack)	0.00J	0.72E-I	0.86E-H	0.83E-H	0.88E-G	**0.66 B**
Smart packaging (Life-span)	0.00J	0.71E-I	1.04EF	0.82E-H	0.89E-G	**0.69 B**
Unpacked (Control)	0.00J	4.00D	5.39C	7.52B	9.21A	**5.22 A**
Mean	**0.00 E**	**1.07 D**	**1.42 C**	**1.82 B**	**2.17 A**	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05.

Discoloration:

The results in **Table (3)** show that the discoloration of green garlic increases significantly as the storage duration increases, these findings are consistent with those of Tanamati et al. (2016). This could be related to the oxidation of phenolic molecules to o-quinones, which is catalyzed by the polyphenol oxidase enzyme. Quinones polymerize into a dark brown polymer, which browns the tissue (Singh et al., 2019). However, all the packaging materials lower the occurrence of discoloration when compared to unpacked (control). Furthermore, active MAP at 3%O_2+5%CO_2 was the most effective treatment for reducing green garlic discoloration. This could be because of low oxygen concentrations around the product tissues, which delays enzymatic browning and reduce the discoloration of the product (Singh et al., 2019). After 20 days, data revealed that active MAP at 3%O_2+5%CO_2 did not show any changes in their color till the end of the storage period, while the smart package modified showed from none to a slight score of discoloration. On the other hand, unpacked garlic (control) resulted in serve discoloration with the highest during the same period.

Table (2). Effect of smart packaging and MAP on General appearance score of green garlic during cold storage at 0°C and RH 90-95% during 2024 and 2025 seasons.

Treatments	Storage periods (days)					
	0	5	10	15	20	Mean
	2024 season					
Passive MAP	9.00a	8.33a	7.00b	6.33bc	4.33ef	**7.00 CD**
Active MAP at (3%+5%)	9.00a	9.00a	9.00a	9.00a	8.33a	**8.87 A**
Smart packaging modified	9.00a	9.00a	8.33a	8.33a	7.00b	**8.33 B**
Smart packaging (Life-pack)	9.00a	7.00b	6.33bc	5.67cd	5.00de	**6.60 D**
Smart packaging (Life-span)	9.00a	9.00a	7.00b	7.00b	5.67cd	**7.53 C**
Unpacked (Control)	9.00a	6.33bc	5.00de	3.67f	1.67g	**5.13 E**
Mean	**9.00 A**	**8.11 B**	**7.11 C**	**6.67 C**	**5.33 D**	
	2024 season					
Passive MAP	9.00a	8.33ab	7.00cd	6.33de	4.33gh	**7.00 C**
Active MAP at (3%+5%)	9.00a	9.00a	9.00a	9.00a	8.33ab	**8.87 A**
Smart packaging modified	9.00a	9.00a	8.33ab	7.67bc	7.00cd	**8.2 B**
Smart packaging (Life-pack)	9.00a	7.00cd	6.33de	5.67ef	5.00fg	**6.60 C**
Smart packaging (Life-span)	9.00a	9.00a	7.67bc	7.00cd	6.33de	**7.8 B**
Unpacked (Control)	9.00a	6.33de	5.00fg	3.67h	1.00i	**5.00 D**
Mean	**9.00 A**	**8.11 B**	**7.22 C**	**6.56 D**	**5.33 E**	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05.

Leaf internal growth:

The results presented in **Table (4)** demonstrate that the sprouting ratio of fresh green garlic increased with prolonged periods of storage. These findings agree with those of El-Sayed et al. (2019), Mechanical injuries in little processed garlic accelerate the respiration and deterioration rates by disrupting membranes and increasing enzymatic activity, resulting in adverse effects. This may result in sprouting growth, reducing the shelf life and marketing quality of garlic (Dronachari et al., 2010)

All packaging material treatments were much more effective at inhibiting sprouting than unpacked (control). Moreover, the active MAP at 3%O_2+5%CO_2 was the most effective treatment for preventing sprouting development, followed by smart packaging modified with no significant difference, while the other treatments were less effective. Unpacked (control) has the highest rating for sprouting growth.

An active MAP can reduce respiratory rate, which limits the energy supply for growth-related events. It can also inhibit some enzymatic steps in the growth activity (Kader, 1986). For fresh garlic, atmospheres with high CO_2 (5–15%) were efficient in delaying sprout development during storage at 0–1°C. High CO_2 atmospheres were able to be inhibiting sprout growth regardless of the initial physiological state (internal sprout development) (Cantwell et al., 2003).

The interaction between packaging materials and storage periods on sprouting was significant. After 20 days, green garlic exposed to active MAP at 3%O_2+5%CO_2 had the lowest value of sprouting.

Table (3). Effect of smart packaging and MAP on discoloration (score) of green garlic during cold storage at 0°C and RH 90-95% during 2024 and 2025 seasons.

Treatments	Storage periods (days)					
	0	5	10	15	20	Mean
	2024 season					
Passive MAP	1.00e	1.00e	1.33de	2.00cd	2.33c	**1.53 B**
Active MAP at (3%+5%)	1.00e	1.00e	1.00e	1.00e	1.00e	**1.00 C**
Smart packaging modified	1.00e	1.00e	1.00e	1.00e	1.33de	**1.07 C**
Smart packaging (Life-pack)	1.00e	1.00e	1.67c-e	2.00cd	3.33b	**1.80 B**
Smart packaging (Life-span)	1.00e	1.00e	1.00e	1.00e	1.67c-e	**1.13 C**
Unpacked (Control)	1.00e	2.33c	3.33b	3.67b	5.00a	**3.07 A**
Mean	**1.00 C**	**1.22 C**	**1.56 B**	**1.78 B**	**2.44 A**	
	2025 season					
Passive MAP	1.00g	1.00g	1.33fg	2.00de	2.33d	**1.53 B**
Active MAP at (3%+5%)	1.00g	1.00g	1.00g	1.00g	1.00g	**1.00 C**
Smart packaging modified	1.00g	1.00g	1.00g	1.00g	1.33fg	**1.07 C**
Smart packaging (Life-pack)	1.00g	1.00g	1.67ef	2.00de	3.33bc	**1.80 B**
Smart packaging (Life-span)	1.00g	1.00g	1.00g	1.00g	1.33fg	**1.07 C**
Unpacked (Control)	1.00g	2.33d	3.00c	3.67b	5.00a	**3.00 A**
Mean	**1.00 D**	**1.22 D**	**1.50 C**	**1.78 B**	**2.39 A**	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05.

Table (4). Effect of smart packaging and MAP on leaf internal growth (mm) of green garlic during cold storage at 0°C and RH 90-95% during 2024 and 2025 seasons.

Treatments	Storage periods (days)					
	0	5	10	15	20	Mean
	2024 season					
Passive MAP	0.50e	0.54e	0.72de	0.83c-e	1.17b-e	**0.75 B**
Active MAP at (3%+5%)	0.50e	0.50e	0.50e	0.53e	0.60e	**0.53 B**
Smart packaging modified	0.50e	0.50e	0.50e	0.77c-e	1.00c-e	**0.65 B**
Smart packaging (Life-pack)	0.50e	0.50e	0.72de	0.67de	1.50bc	**0.78 B**
Smart packaging (Life-span)	0.50e	0.50e	0.63e	0.77c-e	1.00c-e	**0.68 B**
Unpacked (Control)	0.50e	0.50e	1.39b-d	1.83b	3.33a	**1.51 A**
Mean	**0.50 C**	**0.51 C**	**0.74 BC**	**0.90 B**	**1.43 A**	
	2025 season					
Passive MAP	0.50e	0.52e	0.72e	0.82c-e	1.10c-e	**0.73 B**
Active MAP at (3%+5%)	0.50e	0.50e	0.50e	0.53e	0.60e	**0.53 B**
Smart packaging modified	0.50e	0.50e	0.50e	0.77e	1.00c-e	**0.65 B**
Smart packaging (Life-pack)	0.50e	0.50e	0.72e	0.80de	1.40c	**0.78 B**
Smart packaging (Life-span)	0.50e	0.50e	0.63e	0.73e	0.72e	**0.62 B**
Unpacked (Control)	0.50e	0.50e	1.39cd	2.03b	3.83a	**1.65 A**
Mean	**0.50 C**	**0.50 C**	**0.74 BC**	**0.95 B**	**1.44 A**	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05.

Colour (L* value):

The findings presented in **Table (5)** show that the lightness of green garlic decreases significantly with prolonged storage. These findings are consistent with Tanamati et al. (2016). The surface color of the garlic was discovered to be white and changed to a lighter, redder, or more yellow color as the storage duration increased (Kang and Lee, 1999). L* value changes frequently correlated with visual appearance quality assessments (Tanamati et al., 2016).

However, garlic packed in active MAP at 3%O_2+5%CO_2 or smart packaging modified were the best treatments for decreasing the loss of L* value, indicating that the skin surface colour was lighter color (higher L* value) during storage with significant difference between them. While a lower L* value was detected unpacked control, which showed darker color (lower L* value) during storage. Active MAP may be the cause of this, as it lowers metabolic activity, enzyme activity, moisture loss, color loss, browning of the flesh, and increasing the rate at which the organic acids and pigments in fruits and vegetables degrade (Alam and Goyal, 2006). Enzymatic browning, which is brought on by a rise of oxygen, is the reason wherefore the green garlic in the control package turned yellow and reddish more quickly (Singh et al., 2019). According to Banda et al. (2015), the decreased storage temperature also results in a decrease in enzyme activity.

The interaction between packaging materials and storage periods on L* value was significant. After 20 days, green garlic packed to active MAP at 3%O_2+5%CO_2 had the highest value of L* value compared to all packaging materials and unpacked (control) with significant differences between those treatments.

Table (5). Effect of smart packaging and MAP on L* value of green garlic during cold storage at 0°C and RH 90-95% during 2024 and 2025 seasons.

Treatments	Storage periods (days)					
	0	5	10	15	20	Mean
	2024 season					
Passive MAP	76.64 a	73.57 b-g	71.30 g-j	70.21 i-k	68.88 jk	**72.12 CD**
Active MAP at (3%+5%)	76.64 a	75.41 a-c	75.67 ab	75.44 a-c	75.11 a-d	**75.65 A**
Smart packaging modified	76.64 a	74.92 a-e	74.74 a-f	72.95 c-h	71.04 g-j	**74.06 B**
Smart packaging (Life-pack)	76.64 a	72.21 e-i	69.43 jk	70.04 i-k	67.87 kl	**71.24 D**
Smart packaging (Life-span)	76.64 a	74.55 a-f	72.19 f-i	72.68 d-i	70.39 h-k	**73.29 BC**
Unpacked (Control)	76.64 a	65.68 l	62.02 m	61.10 m	57.42 n	**64.57 E**
Mean	**76.64 A**	**72.72 B**	**70.89 C**	**70.40 C**	**68.45 D**	
	2025 season					
Passive MAP	71.64 a	69.57 a-e	66.30 f-i	65.55 f-i	64.79 i	**67.57 C**
Active MAP at (3%+5%)	71.64 a	71.41 a	70.67 a-c	70.44 a-c	70.22 a-d	**70.88 A**
Smart packaging modified	71.64 a	70.92 ab	69.74 a-e	67.95 c-g	66.15 f-i	**69.28 B**
Smart packaging (Life-pack)	71.64 a	68.21 b-f	65.43 g-i	65.04 hi	64.64 i	**66.99 C**
Smart packaging (Life-span)	71.64 a	70.55 a-c	68.19 c-f	67.68 d-h	67.16 e-i	**69.04 B**
Unpacked (Control)	71.64 a	61.68 j	58.02 k	56.10 kl	54.19 l	**60.33 D**
Mean	**71.64 A**	**68.72 B**	**66.39 C**	**65.46 CD**	**64.53 D**	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05.

Gas analysis (CO_2 and O_2 levels):

Changes in headspace atmospheres of packaged green garlic are presented in **Tables (6 and 7).** In both seasons, studying the gas changes inside the package is extremely crucial 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 garlic during the respiration process (Madhav et al., 2016). **Table (6)** shows a gradual change in O_2 level in all packaging materials and along with the storage period, with significant differences with the unpacked control. After 20 days of storage active MAP packaging at 3%O_2+5%CO_2 showed a steady decrease with the progress of the storage time, starting with 3% reaching the levels of 2.56% and 2.75% in the first and second season, respectively. Also, smart packages modified showed the oxygen level inside the package, ranging from 21% to 17.26%, 18.33% in the first and second season, respectively. Carbon Dioxide (CO_2) levels in headspace of the materials packaging of applied packages are shown in **Table (7).** Active MAP 3%O_2+5%CO_2 and Smart package modified showed a regular increase in CO_2 percentage, associated with time progress. This was true in both studied seasons. However, the consumption of O_2 and production of CO_2 in all smart packaging and active MAP treatments were significantly lower than those in passive MAP treatment during the storage period. Furthermore, the lowest consumption of O_2 and production of CO_2 were recorded with green garlic packed in active MAP at 3% O_2+5% CO_2 and smart packaging modified. In contrast, unpacked green garlic showed no changes in O_2 and CO_2 concentration throughout the storage period. These results are consistent with Tanamati et al. (2016) and El-sayed et al. (2019). Chen et al. (2019), who showed that the respiration rates of fresh-cut garlic decreased with a decrease of O_2 concentration and increasing CO_2 concentration; this is the premise for the mechanism of active MAP. This was also confirmed by the variations in O_2 and CO_2 concentrations over the storage period compared to the initial concentration of O_2 and CO_2 on day 0. The results verified that modified atmosphere packaging could substantially extend the storage life of minimally processed garlic. Out of the various combinations of gases used, gas composition of low in O_2 (1-5%) and high in CO_2 (5-10%) was most effective for overall quality retention and extended the shelf-life of fresh-cut fruits and vegetables during modified atmosphere storage (Madhav et al., 2016).

Table (6). Effect of smart packaging and MAP on O_2 % of green garlic during cold storage at 0°C and RH 90-95% during 2024 and 2025 seasons.

Treatments	Storage periods (days)					
	0	**5**	**10**	**15**	**20**	**Mean**
	2024 season					
Passive MAP	21.00 a	18.76 b-e	17.67 d-g	16.58 f-h	15.02 h	**17.81 C**
Active MAP at (3%+5%)	3.00 j	2.89 j	2.82 j	2.74 j	2.56 j	**2.80 D**
Smart packaging modified	21.00 a	20.45 ab	19.94 a-c	19.43 a-d	17.26 e-g	**19.62 B**
Smart packaging (Life-pack)	21.00 a	20.62 ab	19.49 a-d	18.35 c-f	16.70 f-h	**19.23 B**
Smart packaging (Life-span)	21.00 a	20.03 a-c	18.84 b-e	12.13 i	16.18 gh	**17.64 C**
Unpacked (Control)	21.00 a	21.00 a	21.00 a	21.00 a	21.00 a	**21.00 A**
Mean	**18.00 A**	**17.29 AB**	**16.63 B**	**15.04 C**	**14.79 C**	
	2025 season					
Passive MAP	21.00 a	18.96 de	17.95 f	16.26 g	14.48 h	**17.73 E**
Active MAP at (3%+5%)	3.00 i	2.91 i	2.88 i	2.81 i	2.75 i	**2.87 F**
Smart packaging modified	21.00 a	20.80 a	19.85 bc	19.63 b-d	18.33 ef	**19.92 B**
Smart packaging (Life-pack)	21.00 a	20.32 ab	19.34 cd	18.28 ef	16.53 g	**19.10 C**
Smart packaging (Life-span)	21.00 a	20.02 bc	18.47 ef	16.42 g	16.75 g	**18.53 D**
Unpacked (Control)	21.00 a	21.00 a	21.00 a	21.00 a	21.00 a	**21.00 A**
Mean	**18.00 A**	**17.34 B**	**16.58 C**	**15.73 D**	**14.97 E**	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05.

Table (7). Effect of smart packaging and MAP on CO_2% of green garlic during cold storage at 0°C and RH 90-95% during 2024 and 2025 seasons.

Treatments	Storage periods (days)					
	0	5	10	15	20	Mean
	2024 season					
Passive MAP	0.03 o	0.78 n	1.82 i-k	2.86 gh	4.52 de	**2.00 BC**
Active MAP at (3%+5%)	5.00 d	5.66 c	6.01 bc	6.35 ab	6.83 a	**5.97 A**
Smart packaging modified	0.03 o	1.19 l-n	2.26 h-j	3.33 fg	4.33 e	**2.23 B**
Smart packaging (Life-pack)	0.03 o	1.07 mn	1.73 j-l	2.40 hi	3.63 f	**1.77 C**
Smart packaging (Life-span)	0.03 o	0.77 n	1.09 mn	1.42 k-m	2.76 gh	**1.21 D**
Unpacked (Control)	0.03 o	0.03 o	0.03 o	0.03 o	0.03 o	**0.03 E**
Mean	**0.86 E**	**1.58 D**	**2.16 C**	**2.73 B**	**3.69 A**	
	2025 season					
Passive MAP	0.03 p	0.28 op	1.53 k-m	2.33 ij	4.42 ef	**1.72 C**
Active MAP at (3%+5%)	5.00 de	5.50 cd	5.74 bc	6.15 ab	6.51 a	**5.78 A**
Smart packaging modified	0.03 p	0.99 mn	2.00 i-k	3.00 gh	4.27 f	**2.06 B**
Smart packaging (Life-pack)	0.03 p	1.03 mn	1.73 j-l	2.43 hi	3.53 g	**1.75 C**
Smart packaging (Life-span)	0.03 p	0.83 no	1.05 mn	1.35 l-n	2.39 hi	**1.13 D**
Unpacked (Control)	0.03 p	0.03 p	0.03 p	0.03 p	0.03 p	**0.03 E**
Mean	**0.86 E**	**1.44 D**	**2.01 C**	**2.55 B**	**3.53 A**	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05.

Titratable acidity (TA) content:

Results in **Table (8)** demonstrate that the TA content generally tended to decrease regularly during the storage period. According to Selcuk and Erkan (2014), who found that the observed decrease in acidity with ripening could be attributed to a variety of factors, including the transformation of acids into other compounds and the reduced ability of fruits to synthesize acids,

All treatments gave significantly the highest value of TA in green garlic as compared with unpacked control in the first season. While the active MAP at $3\%O_2+5\%CO_2$ was the higher value treatment in TA with significant different compared to the other treatments and the unpacked control. These results may be due to these materials slowing down respiration and metabolic activity, hence retarding the ripening process and delaying the utilization of organic acids (Ali et al., 2011).

After 20 days of storage, green garlic treated to active MAP at $3\%O_2+5\%CO_2$ was the most effective treatment in maintaining TA and resulted in higher value TA, while unpacked control gave the lowest ones in the same period. These results were achieved in the two seasons.

Table (8). Effect of smart packaging and MAP on TA percentage of green garlic during cold storage at 0°C and RH 90-95% during 2024 and 2025 seasons.

Treatments	Storage periods (days)					
	0	5	10	15	20	Mean
			2024 season			
Passive MAP	2.90 a	2.72 b-e	2.62 d-g	2.51 f-k	2.42 i-k	**2.63 B**
Active MAP at (3%+5%)	2.90 a	2.86 ab	2.79 a-c	2.72 b-e	2.63 d-g	**2.78 A**
Smart packaging modified	2.90 a	2.74 b-d	2.65 c-f	2.55 f-i	2.43 i-k	**2.65 B**
Smart packaging (Life-pack)	2.90 a	2.49 g-k	2.44 h-k	2.38 k-m	2.25 lm	**2.49 C**
Smart packaging (Life-span)	2.90 a	2.63 d-g	2.58 e-h	2.52 f-k	2.41 jk	**2.61 B**
Unpacked (Control)	2.90 a	2.54 f-j	2.39 kl	2.24 m	2.05 n	**2.43 D**
Mean	**2.90 A**	**2.66 B**	**2.58 C**	**2.49 D**	**2.36 E**	
			2025 season			
Passive MAP	2.90 a	2.69 c-e	2.56 e-g	2.51 f-j	2.40 h-j	**2.61 B**
Active MAP at (3%+5%)	2.90 a	2.86 ab	2.80 a-c	2.72 b-d	2.63 d-f	**2.78 A**
Smart packaging modified	2.90 a	2.85 ab	2.66 c-f	2.53 f-h	2.43 g-j	**2.67 B**
Smart packaging (Life-pack)	2.90 a	2.51 f-i	2.38 i-k	2.38 h-k	2.18 l	**2.47 C**
Smart packaging (Life-span)	2.90 a	2.64 d-f	2.64 c-f	2.52 f-i	2.46 g-j	**2.63 B**
Unpacked (Control)	2.90 a	2.52 f-i	2.36 jk	2.24 kl	1.98 m	**2.40 C**
Mean	**2.90 A**	**2.68 B**	**2.57 C**	**2.48 D**	**2.35 E**	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05.

Pyruvic acid content:

As indicated in **Table (9),** Green garlic's total pungency content (μ mol pyruvic acid/100 gm F.W.) reduced progressively during storage. A similar reduction was noted in the control bulb. Cantwell et al. (2003) found the same results with green garlic. This could be due to the hydrolysis of polysaccharides and non-reducing sugars, which use acid to convert them to hexose sugars, as well as the degradation of pungency ingredients, as well as cell disruption produced by substance volatilization and leaching (Berno et al., 2014).

All packaging treatments had significantly higher pyruvic acid content as compared with unpacked (control) during the storage period in second season. However, green garlic packed in active MAP at 3% O_2+5% CO_2 or smart packaging modified were the most effective treatments in maintaining total pyruvic acid content with no significant differences between them, followed by smart packaging (Life-pack and Life-span) with no significant differences between them. On the other hand, the unpacked (control) recorded the lowest significant values. The results obtained agreed with those of (El-Sayed et al., 2019) on green garlic. 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).

The interaction between packaging materials treatments and storage period after 20 days, obviously had positive effect on Pyruvic acid content in both seasons. It clear that the active MAP at 3%O_2+5%CO_2 had the highest value of Pyruvic acid content during the various storage periods in both seasons.

Table (9). Effect of smart packaging and MAP on Pyruvic acid content (µ mol/100 gm F.W.) of green garlic during cold storage at 0°C and RH 90-95% during 2024 and 2025 seasons.

Treatments	Storage periods (days)					
	0	**5**	**10**	**15**	**20**	**Mean**
			2024 season			
Passive MAP	20.97 bc	20.00 cd	18.78 ef	17.57 gh	16.23 i-k	**18.71 C**
Active MAP at (3%+5%)	20.97 bc	21.27 b	21.53 ab	21.80 ab	21.23 b	**21.36 A**
Smart packaging modified	20.97 bc	22.53 a	21.30 b	20.07 cd	19.43 de	**20.86 A**
Smart packaging (Life-pack)	20.97 bc	20.07 cd	19.83 c-e	19.60 de	15.67 k	**19.23 B**
Smart packaging (Life-span)	20.97 bc	19.53 de	19.45 de	19.37 de	17.23 g-i	**19.31 B**
Unpacked (Control)	20.97 bc	19.53 de	18.17 fg	16.87 h-j	15.83 jk	**18.27 C**
Mean	**20.97 A**	**20.49 B**	**19.84 C**	**19.21 D**	**17.61 E**	
			2025 season			
Passive MAP	20.97 a	19.53 b-e	19.42 b-e	18.33 e	16.50 f	**18.95 C**
Active MAP at (3%+5%)	20.97 a	20.73 ab	19.85 a-d	19.60 a-e	20.03 a-d	**20.24 A**
Smart packaging modified	20.97 a	20.67 a-c	20.33 a-d	19.77 a-d	19.43 b-e	**20.23 A**
Smart packaging (Life-pack)	20.97 a	20.07 a-d	19.55 b-e	19.30 c-e	15.73 fg	**19.12 BC**
Smart packaging (Life-span)	20.97 a	19.23 de	20.00 a-d	19.50 b-e	18.30 e	**19.60 B**
Unpacked (Control)	20.97 a	19.23 de	18.30 e	16.70 f	15.00 g	**18.04 D**
Mean	**20.97 A**	**19.91 B**	**19.58 B**	**18.87 C**	**17.50 D**	

The values that contain the same capital or small letters in the same columns and rows indicate that there are no significant variations between each other at level 0.05

CONCLUSIONS

Green garlic (*Allium sativum* L.) cv. "Balady" stored at active MAP at 3%O_2+5%CO_2 and smart packaging modified maintained a superior quality of garlic during storage. However, active MAP at 3%O_2+5%CO_2 is the best treatment for reducing weight loss %, retaining significantly higher L* value, TA, pyruvic acid content, and gave an excellent appearance for 20 days of storage without any leaf external growth or discoloration, but the smart packaging modified gave an excellent visual general appearance for 15 days and rated good appearance after 20 days.

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Unpack (control) after 20 during cold storage at 0°C and RH 90-95%

Active MAP at 3%O_2+ 5%CO_2 after 20 days during cold storage at 0°C and RH 90-95%

Smart packaging modified after 20 days during cold storage at 0°C and RH 90-95%

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الملخص العربي

تأثير العبوات الذكية والجو الهوائي المعدل على تحسين القدرة التخزينية والمحافظة على صفات الجودة للثوم الأخضر اثنـاء التخـزين المـبرد

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أجري البحث لدراسة تأثير العبوات الذكية (Life-Span packaging, Lifepack® and smart packaging modified)، والتعبئة في جو هوائي معدل موجب بتركيز 3% أوكسجين، 5% ثاني أكسيد الكربون والجو الهوائي المعدل السالب مقارنة بالغير مغلفة (كنترول) وتأثيرها في الحفاظ على خصائص الجودة وتحسين القدرة التخزينية للثوم الأخضر أثناء التخزين المبرد عند صفر مئوية ورطوبة نسبية 90-95٪ لمدة 20 يومًا خلال موسمي الدراسة 2024 و2025. أشارت النتائج ان جميع معاملات التغليف المستخدمة تفوقت على المعاملة غير المغلفة كنترول في الحفاظ على جودة الثوم الأخضر واطالة فترة التخزين. بينما كانت التعبئة في الجو الهوائي المعدل الموجبة بتركيز 3% أوكسجين، 5% ثاني أكسيد الكربون هي أفضل المعاملات التي أدت الي تقليل نسبة الفقد في الوزن كما حافظت على البريق (L* value) والحموضة وعلى حمض البيروفيك وايضا أعطت مظهرًا ممتازًا بعد 20 يومًا من التخزين المبرد دون أي نمو خارجي للأوراق أو تغير في اللون أو تجذير، بينما أدت معاملة العبوات الذكية المعدلة مظهر جيد في نفس الفترة الزمنية.