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Preserving Freshness: Unveiling the Power of Modified Atmospheric Packaging for Extended Shelf Life of Peeled Garlic Cloves

H. Bagul[1], V. A. Salve[2], K. J. Kamble[3] and V. P. Kad[4]
Dept. of Process and Food Engg., Dr. Annasaheb Shinde College of Agriculture Engineering and Technology
Mahatma Phule Krishi Vidyapeeth, Rahuri - 413722
email: - harshalbagulagri99@gmail.com
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Abstract

This comprehensive study delves into a myriad of innovative techniques for extending the shelf life of minimally processed garlic cloves (*Allium Sativum* L.). Our goal is to uncover a convenient and effortless preservation method that ensures the availability of ready-to-use, waste-free garlic cloves. Through an extensive review of relevant literature, we have identified the modified atmospheric packaging (MAP) method as the most suitable approach for storing peeled garlic cloves, without the need for any chemical coatings on the delectable cloves. By creating a controlled modified atmosphere consisting of optimal nitrogen (N_2 %) and carbon dioxide (CO_2 %) levels, MAP significantly reduces the cloves' respiration rate, thereby enhancing their shelf life and ensuring their long-lasting freshness.

Key words : Peeled garlic cloves, Pre-treatment, Quality parameters, Modified atmospheric packaging, Shelf life.

Garlic is widely available in various processed forms such as garlic paste, garlic powder, and garlic flavouring agents. However, there is a consistent demand for the utilization of fresh garlic cloves without any processing. Unfortunately, the production of fresh garlic cloves may not always meet this demand. To address this issue, an alternative approach can be adopted where garlic cloves are peeled and packaged in modified atmospheric packs (MAP) with suitable combinations of gases. The utilization of MAP is particularly relevant because when garlic cloves are exposed to the environment, their respiration rate increases, leading to detrimental effects on quality factors such as physical loss in weight (PLW), antioxidant activity, ascorbic acid content, microbial count, colour, smell, and flavour. These factors contribute to the deterioration of garlic cloves. By employing MAP, the surrounding atmosphere can be regulated to preserve the peeled garlic cloves, effectively increasing their shelf life while minimizing the risk of quality degradation. This approach allows for the supply of fresh garlic cloves to meet the demand without compromising on the product's quality.

Garlic (*Allium sativum* L.) is a fascinating member of the Alliaceae family, renowned as one of the most popular allium vegetables worldwide, second only to onions. With its origins tracing back to South Asia and Central Asia, this remarkable spice has been cherished for thousands of years, enriching culinary traditions across the globe. In the realm of garlic production, China stands as the undisputed leader, yielding an impressive 20.7 million tons in 2020. Meanwhile, India emerges as a strong contender, securing the second position with a notable production of 2.9 million tons during the same year, showcasing the country's dedication to garlic cultivation. Remarkably, Madhya Pradesh, a state in India, spearheaded the garlic production charts in the financial year 2022, boasting a staggering harvest of over 1,904,682

1. M. Tech Student, 2. Assistant Professor, 3. Head of Department and 4. Associate Professor.

tonnes. While Maharashtra may rank 10th in garlic production across India, it still contributes a significant annual output of 22,256 tonnes, adding its own flavourful touch to the nation's garlic production landscape. Additionally, the United States holds a prominent role as the largest importer of Indian garlic, further solidifying the global demand for this versatile spice. Notably, the bustling Nhava-Sheva port in Mumbai serves as a vital gateway for exporting garlic to diverse corners of the world, connecting international palates with the aromatic delights of India's garlic harvest. (Anonymous, a. 2021).

Garlic, a humble bulb bursting with remarkable properties, boasts over 200 compounds that actively contribute to the prevention of various heart diseases. Its potent arsenal encompasses the ability to inhibit and eradicate harmful bacteria, fungi, and parasites. But that's not all, garlic's extraordinary benefits extend further, safeguarding against blood clotting, fortifying the liver, and even displaying anti-tumour properties. Encapsulated within its cloves, sulphur-containing compounds embark on a mission to safeguard our well-being by invigorating the production of valuable enzymes. A particular chemical named Ajoene, residing within garlic's essence, assumes the role of a guardian, diligently thinning the blood and thwarting the formation of clots, thereby alleviating hypertension. In the enchanting world of garlic's gustatory allure, the true magic unfolds through the enzymatic breakdown of alkyl-L-cysteine sulfoxide flavour precursors. This alchemical transformation, masterfully orchestrated by alliinase, ushers forth pyruvate, ammonia, and an enchanting array of volatile and non-volatile sulphur compounds. It is this aromatic symphony that we perceive as the quintessential essence and flavour of garlic. Beyond its tantalizing taste, garlic's alliin emerges as the leading protagonist-a biologically active entity that imparts invaluable medicinal benefits. Its functional prowess extends to antimicrobial and anticancer activities, bolstered by its antioxidative and antidiabetic properties. Embracing garlic's therapeutic potential, the human body discovers a myriad of responses-a reduction in risk factors for cardiovascular diseases, invigorated immune function, enhanced detoxification of foreign compounds, and the restoration of physical vigour. Furthermore, garlic's indomitable spirit endows resilience against diverse stresses, potentially unveiling an anti-aging elixir (Rahman *et al.*, 2007). Plunging into the depths of garlic's nutritional and medicinal reservoir, one discovers a treasure trove of sulphur compounds, including alliin, allicin, diallyl sulphide, and ajoene. Complemented by a symphony of water, cellulose, amino acids, lipids, enteric oil, fructose complexes, steroid saponosides, organic acids, and a bevy of minerals (such as magnesium, zinc, selenium, and germanium), garlic stands as a nutritional powerhouse. And with allicin and other sulphur compounds as its emissaries, garlic's enchanting bouquet imparts a miraculous blend of antibiotics, antibacterial wonders, and antifungal prowess, safeguarding our health and well-being (Santosha *et al.*, 2013).

Garlic (*Allium sativum* L.) is a widely recognized spice known for its rich biochemical composition, particularly its abundance of allicin and polyphenols. This versatile herb has been utilized worldwide as both a medicinal herb and a flavouring agent (Feng *et al.*, 2019; Papu *et al.*, 2014). Extensive epidemiological studies have demonstrated the numerous health benefits of garlic, including its role in preventing cardiovascular diseases, its anti-cancer properties, and its ability to combat pathogenic microorganisms, thanks to the presence of these bioactive components (Zhou *et al.*, 2017).

One challenge faced by garlic sellers is its high-water content, which exceeds 75% on a web basis. This high-water content renders fresh garlic cloves prone to quick germination and rotting during storage, leading to a shorter shelf life and significant economic losses (Feng *et al*., 2020; Papu *et al*., 2014). Across different regions of the world, garlic (*Allium sativum* L.) holds a significant place in culinary traditions. It is also renowned for its diverse biological activities, including antibacterial, antithrombotic, antihypertensive, antitumor, antimicrobial, anti-cholesterol, and anti-aging properties (Kim *et al*., 2014; Martins *et al*., 2016).

The composition of garlic cloves includes approximately 28% carbohydrates, 2.3% organosulfur compounds, 2% proteins, 1.5% fibre, and 1.2% free amino acids (Omar and Al-Wabel, 2010). The sulphur-containing compounds in garlic are primarily responsible for its characteristic flavour and numerous health benefits. Among these compounds, (+)-S-allyl-L-cysteine sulfoxide, also known as alliin, plays a crucial role. When garlic cells are disrupted, the enzyme alliinase converts the odourless alliin into allicin (diallyl thiosulfinate), which gives garlic its distinct aroma and therapeutic properties (Santhosha *et al*., 2013; Prati *et al*., 2014). However, allicin is highly unstable and decomposes into various lipophilic organosulfur compounds, such as diallyl disulfide, diallyl sulphide, dithiins (2-vinyl-1,3-dithiin, 3-vinyl-1,2-dithiin), diallyl trisulfide, and E/Z-ajoene (Ferioli *et al*., 2020).

The demand for peeled garlic is steadily increasing in both retail and food markets. Salty

Plate (a): Peeled Garlic Cloves at 3rd Day of Peeling, Black Mold Growth (*Aspergillus Niger*)

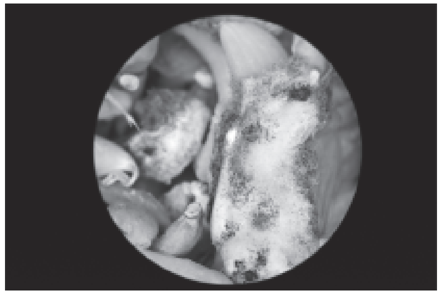

Plate (b): *Aspergillus Niger* Under Electronic Microscope

(Image Source: Actual Experiment of MAP of peeled garlic cloves performed at Dr. A.S.C.A.E.T. (MPKV) Rahuri.2023)

food producers, including pickle and olive manufacturers, as well as large-scale consumers such as restaurants and hotels, prefer ready-to-use peeled garlic. However, the peeling process reduces the shelf life of garlic cloves due to weight and aroma losses, surface discoloration, and the risk of microbial spoilage. The peeled garlic cloves are more susceptible to perishing as the tissue is injured, providing a larger surface area for exposure and potential microbial contamination. Additionally, sprouting and rooting are quality issues that arise from storing peeled garlic cloves in high humidity conditions and at temperatures higher than the recommended range of 0-2°C (Cantwell *et al*., 2003).

Reviews

Modified atmospheric packaging (MAP) technology : Modified atmospheric packaging (MAP) technology is a valuable preservation system that effectively extends the shelf life of fruits and vegetables. By altering the composition of the atmosphere within the packaging, MAP leverages the dynamic interaction between the metabolic processes of the packaged product. The primary objective of this system is to achieve an optimal balance in the internal gas composition, thereby slowing down the respiration rate and preserving the product (Diego *et al*., 2017). Plastic films are commonly employed in MAP to prolong the storage life of freshly prepared or cut vegetables. The modified atmosphere (MA) within the packaging, characterized by low oxygen (O_2) levels and elevated carbon dioxide (CO_2) concentrations, effectively reduces the respiration rate and retards the degree of degradation (Park *et al.*, 1999).

By introducing oxygen into the packaging atmosphere, anaerobic respiration is prevented, and the growth of aerobic spoilage microorganisms is inhibited. However, it is crucial to maintain low residual oxygen levels in

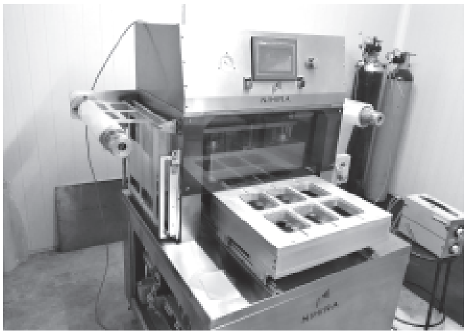

Plate (c): Modified Atmospheric Packaging Machine

Plate (d): Modified Atmospheric Packaging of Peeled garlic cloves

(Image Source: Actual Experiment of MAP of peeled garlic cloves performed at Dr. A.S.C.A.E.T. (MPKV) Rahuri.2023; MAP Industry: NIHIRA FOOD Industry Bhosari, Pune)

the package atmosphere to enhance the shelf life of the produce. Carbon dioxide plays a pivotal role in MAP as it exhibits bacteriostatic and fungistatic properties. Its presence inhibits the growth of numerous spoilage bacteria, and this inhibition is further enhanced with higher concentrations of CO_2 in the atmosphere. Additionally, CO_2 slows down enzymatic activity, thereby extending the shelf life and preserving the quality of the produce. Nitrogen (N_2), an inert and tasteless gas, is used as a filler gas in MAP. Its purpose is to displace oxygen from the packages. Nitrogen does not support the growth of aerobic microbes, thus inhibiting their proliferation. It does't impede the growth of anaerobic bacteria (Sandya *et al.*, 2010).

Studies on MAP on different fruits and vegetables : In order to prolong the shelf-life of strawberries after they have been harvested, various methods have been explored. One effective approach involves utilizing a composite membrane made of low-density polyethylene, which helps to retard the respiration rate and minimize weight loss. Zhang *et al.*, (2003) found that by exposing strawberries to a controlled gas environment consisting of 2.5% oxygen (O_2) and 16% carbon dioxide (CO_2), the strawberries could be preserved for an extended period of 4-6 days. Another study conducted by Nielsen *et al.*, (2008) focused on packaging strategies to maintain the quality of strawberries. They discovered that storing strawberries in micro perforated polypropylene bags with a specific gas composition of 11-14% CO_2 and 9-12% O_2 resulted in better weight and appearance retention compared to leaving the fruits unpackaged for 10 days at a temperature of 50°C. These findings highlight the potential of controlled gas environments and appropriate packaging techniques as effective methods for enhancing the post-harvest lifespan of strawberries.

A study was conducted to investigate the impact of different storage conditions, specifically varying oxygen (10% O_2), carbon dioxide (20% CO_2), and nitrogen (70% N_2) levels, on the storability of shredded cabbage. The researchers examined the effects of different packaging materials, namely glass jars, polyethylene (PE), and polypropylene (PP), during a 7-day storage period at temperatures of 0°C and 10°C. Interestingly, they observed that at 10°C, there was a greater variation in CO_2 and O_2 concentrations compared to 0°C. When the O_2 levels dropped below 3-5% and CO_2 levels rose above 2-5%, the cabbage underwent anaerobic metabolism. The most favourable outcomes were obtained by packaging fresh cut cabbage in polyethylene film with an initial atmosphere consisting of 10% O_2 and storing it at 0°C (Plestenjak *et al.*, 2008).

A study conducted by (Rai *et al.*, in 2011) investigated the impact of modified atmosphere packaging (MAP) on the shelf-life of jamun fruit, as well as its biochemical, microbiological, and physiological changes. The experiment compared the effects of perforated and non-perforated polypropylene film, with a MAP condition consisting of 2% O_2 and 15% CO_2. Notably, the results demonstrated that the retention of ascorbic acid content, flavonoids, and anthocyanin content was significantly better in packages that incorporated a single macro-perforation. These benefits were observed when the jamun fruit was stored at 5°C and 75% relative humidity (RH) for a period of 23 days.

In a study conducted by Porat *et al.*, in 2004, the effectiveness of different types of perforated films in reducing the development of rind disorder in citrus fruits was examined. The results revealed that micro perforated films, which maintained oxygen levels at 2-3% and carbon dioxide levels at 19-20% inside the packaging, exhibited superior performance compared to macro perforated films. These findings suggest that controlling the gas composition with micro perforated films can significantly mitigate rind disorder, highlighting the importance of selecting appropriate packaging materials for preserving citrus fruit quality.

in a study conducted by Aryanpooya *et al.*, (2010), it was observed that utilizing MAP with 15% oxygen (O_2), 10% carbon dioxide (CO_2), and 75% nitrogen (N_2) proved highly effective in maintaining the quality of "Erdijubilem" and "Erdibotermo" sour cherry fruits. Over a span of 42 days at a temperature of 0°C, this approach resulted in improved pH levels, titratable acidity, minimized weight loss, sustained colour retention, as well as maintained soluble solids content (SSC) and sugar/acid ratio.

Similarly, Sabir *et al.*, (2010) investigated the impact of MAP in combination with ethanol treatments on the preservation of stemless grapes (cv. 'Muskule' V. viniferal.). The findings revealed that the application of ethanol and MAP led to delayed alterations in factors such as fresh weight loss, SSC, pH, and berry decay. Moreover, these treatments effectively slowed down the rate of respiration, resulting in enhanced overall quality and extended storage life of the grapes. By employing such strategies, it is possible to effectively maintain the freshness and quality of various fruits over extended periods, ensuring greater consumer satisfaction and reduced product waste.

A study focused on the application of active modified atmospheric packaging (MAP) for preserving minimally processed bell peppers demonstrated noteworthy findings. According to Monolopoulou *et al.*, (2012), the research outcomes indicated that utilizing a MAP composition of 5% oxygen (O_2) and 10% carbon dioxide (CO_2) led to significant improvements. These included reduced mass loss, better retention of firmness, preserved skin color, enhanced visual quality, and an extended qualitative shelf-life of up to 10 days at 0°C when compared to storage at 5°C. This study highlights the potential benefits of implementing active MAP techniques to maintain the freshness and quality of minimally processed bell peppers, providing consumers with a prolonged window of optimal product enjoyment.

An investigation was conducted to evaluate the impact of modified atmospheric packaging (MAP) and low temperature storage on preserving the quality of oyster mushrooms (Pleurotus florida). The study compared two techniques aimed at enhancing the physicochemical attributes of the mushrooms. The mushrooms were subjected to packaging with varying gas compositions, and it was found that MAP, with a gas composition of 5% CO_2 and 10% O_2, yielded superior results in terms of retaining quality characteristics and receiving higher sensory ratings. The findings demonstrated that both MAP and optimized storage conditions effectively maintained the quality of oyster mushrooms, significantly extending their postharvest lifespan up to 25 days at a temperature of 4°C (Jafri *et al.*, 2013).

According to a study conducted by Mampholo *et al.* in 2013, the application of modified atmosphere storage (with 2% O_2 and 7% CO_2) on Chinese cabbage packaged in bi-oriented polypropylene packaging has shown improved results in terms of ascorbic acid, carotenoids, total phenolic compounds, and antioxidant scavenging activity. These positive effects were observed during a 10-day storage period at 10°C.

According to a study conducted by Venkatram *et al.*, in 2016, the impact of modified atmosphere packaging (MAP) on the physio-chemical characteristics of "Balanagar" custard apple was examined. The fruits were packaged in polypropylene bags and subjected to different gas concentrations, including 3% O_2 + 5% CO_2 or 3% O_2 + 10% CO_2, 5% O2 + 5% CO_2 5% O_2 + 10% CO_2, and air packaging, all stored at a temperature of 15°C. The findings revealed that the fruits packaged in 3% O_2 + 10% CO_2 exhibited the lowest postharvest weight loss (PLW). Moreover, the combination of 5% O_2 + 10% CO_2 resulted in the highest firmness of the fruits. It was observed that 5% O_2 + 5% CO_2 or 5% O_2 + 10% CO_2 prolonged the ripening process, taking the maximum number of days for ripening. Furthermore, 3% O_2 + 5% CO_2 demonstrated lower spoilage rates. Interestingly, the MAP approach, regardless of the O_2 + CO_2 concentration, significantly enhanced the ascorbic acid content in the fruits. Based on these findings, it can be concluded that "Balanagar" custard apple fruits packaged in MAP with a concentration of 3% O_2 + 5% CO_2 and stored at 15°C exhibited the maximum shelf-life.

A study conducted by Moor *et al.*, (2014) aimed to investigate the impact of different modified atmosphere packaging (MAP) techniques on the postharvest quality of the raspberry variety "Polka." The researchers utilized passive MAP and active MAP with LDPE bags flushed with a gas mixture containing 10% O_2 and 15% CO_2. For comparison, a control group of raspberries was stored in microperforated punnets under normal atmospheric conditions. After three days of storage at a temperature of 1.6°C, the raspberries stored in passively modified LDPE bags exhibited superior quality when compared to the control group. The specific observations made during the study provided valuable insights into the effects of different MAP techniques on the postharvest preservation of raspberries.

According to a study conducted by Antala *et al.*, in 2014, the impact of employing active Modified Atmosphere Packaging (MAP) on sapota fruit (Kalipatti) was investigated. The fruit was pre-treated with 200 ppm benomyle for a duration of 5 minutes and subsequently stored at two different temperatures: 60°C and 110°C. The gas composition used in the LDPE bags consisted of two variations: 5% O2 + 5% CO2 and 5% O_2 + 10% CO_2.

Remarkably, the findings revealed that by utilizing LDPE bags with a gas concentration of 5% O_2 + 10% CO_2 and storing the sapota fruit at 60°C, its shelf-life could be extended up to 49 days. Furthermore, after this period, the fruit required an additional three days under ambient conditions to ripen fully. This indicates that the chosen packaging method and controlled storage conditions significantly contributed to the enhanced preservation and delayed ripening of sapota fruit. These results shed light on the potential benefits of active MAP techniques in maintaining the quality and extending the shelf-life of sapota fruit, ultimately offering economic advantages to producers and consumers alike.

In a comprehensive investigation conducted by Liguori *et al*., in 2015, the quality assessment of "Red Globe" table grapes was examined in relation to their packaging materials and storage conditions. The study focused on the effects of passive and active modified atmosphere packaging (MAP) methods, coupled with ultraviolet-C treatment. The grapes were carefully packaged in rigid polypropylene boxes and sealed using either a micro perforated polypropylene film or a continuous polyethylene film. To replicate real-world scenarios, the grapes were stored at 5°C for an initial duration of 21 days, followed by subsequent storage at 20°C for an additional 6 days. These findings provide valuable insights into the optimization of packaging strategies for "Red Globe" table grapes, highlighting the significance of employing polypropylene containers over polyethylene alternatives in MAP. By meticulously controlling the storage conditions and utilizing appropriate packaging materials, stakeholders within the agricultural and food industry can ensure the extended shelf life and overall quality of these popular grape cultivars.

In a study conducted by Liguori *et al*., in 2015, the impact of different packaging materials on the quality of "Vitoria" and "Red Globe" table grapes under extreme temperature conditions was investigated. Two packaging methods were compared: micro perforated polypropylene film (passive MAP) and non perforated polyethylene (active MAP with a gas mixture of 20% CO_2 and air, as well as 5% O_2 and 15% CO_2 with N_2). Interestingly, the results demonstrated that the fruits enclosed in micro perforated polypropylene packages exhibited remarkable improvements in various quality parameters compared to those in the non perforated polyethylene packages. During the initial 14 days of storage at a high temperature of 50°C, the grapes in the micro perforated polypropylene film experienced significantly lower weight loss, indicating better moisture retention within the fruit. Moreover, the grapes in the micro perforated packages showed superior levels of Total Soluble Solids (TSS), which is a measure of sweetness, and titratable acidity, an indicator of freshness and taste. These grapes also exhibited enhanced crunchiness, juiciness, and maintained their overall texture.

Modified Atmospheric Packaging of Peeled Garlic Cloves : A study conducted by Mehmet Torun *et al*., (2021) examined the effect of edible protein coatings, specifically zein and milk protein, on the shelf life of peeled garlic cloves. The study monitored the cloves for 45 days at 15°C. The results indicated that milk protein-treated films exhibited superior mechanical properties, while zein-based films showed better water vapor permeability. The researchers concluded that coating the garlic cloves with these proteins can effectively control the loss and decomposition of flavour during storage. The weight loss and texture results showed that garlic samples coated with milk protein could be stored for up to 10 days, while those coated with zein could be stored for up to

15 days at 15°C. Hence, the study revealed that both milk protein and zein coatings can extend the shelf life of garlic cloves at this temperature.

In a study by Sharma P.*et al*., (2020), the impact of different doses of gamma rays (ranging from 0 to 2.5 kGy) and packaging types (polypropylene, perforated polypropylene, vacuum packages) on the acceptable shelf life of minimally processed garlic cloves under refrigerated conditions was investigated. The highest overall acceptability scores were obtained for garlic cloves irradiated at 2.5 kGy, regardless of the packaging used. However, the quality parameters slightly decreased at this dose treatment. The study revealed that minimally processed garlic cloves maintained their best quality for 77 days in refrigerated storage (4 ± 1°C; 65 ± 5% RH) when they were irradiated with gamma rays at a dose of 1.5 kGy and packaged in polypropylene packages of 150 gauge.

Fouzia S. *et al*., (2021) conducted observations on ten-day-old garlic sprouts that were gamma irradiated within the range of 0.25-1.25 kGy. The sprouts were then stored under refrigerated conditions (3 ± 1°C, RH 85%) for 15 days. The results demonstrated that a gamma irradiation treatment of 1.25 kGy significantly ($p \leq 0.05$) preserved the external appearance, texture, and appeal of the irradiated sprouts throughout the storage period. This finding highlights the effectiveness of gamma irradiation in maintaining the quality of garlic sprouts during refrigerated storage.

Mehmet *et al*., (2017) conducted a study to investigate the effect of different gas compositions within the package on the quality characteristics of peeled garlic. The samples were packaged with atmospheric compositions of 5% CO_2, 15% CO_2, and 25% CO_2, and then stored for 30 days at 15°C. The results revealed that the weight loss in the samples ranged from 3.00% to 4.13%. Additionally, the garlic cloves packaged under modified atmosphere packaging (MAP) compositions of 5%, 15%, and 25% CO_2 showed respective sugar losses of 7%, 11%, and 17% by the end of the storage period. This suggests that the gas composition within the package significantly affects the quality and shelf life of peeled garlic cloves.

Tanamati F. *et al*., (2016) conducted a study on the packaging of peeled garlic cloves using modified atmosphere packaging (MAP) with varying concentrations of oxygen (5%, 10%, 15%) and corresponding carbon dioxide levels of 23%, 15%, and 8%. The samples were stored at different temperatures (0°C, 5°C, 10°C). The study found that excellent visual quality of the garlic cloves was maintained for up to 16 days at 5°C, while acceptable quality was maintained for approximately 10 days at 10°C. These

Plate (e): 6^{th} Day of MAP Peeled Garlic Cloves Stored at 5°C Temperature

Plate (f): 6^{th} Day of MAP Peeled Garlic Cloves Stored at 10°C Temperature

(Image Source: Actual Experiment of MAP of peeled garlic cloves performed at Dr. A.S.C.A.E.T. (MPKV) Rahuri.2023) findings suggest that the MAP concentrations of oxygen and carbon dioxide, along with the storage temperature, play a crucial role in preserving the quality and extending the shelf life of peeled garlic cloves.

A study conducted by Venu J. *et al*., (2016) aimed to evaluate the quality of minimally processed garlic cloves from two Indian varieties during storage using modified atmosphere packaging (MAP). The study selected oxygen concentrations of 1%, 2%, and 3%, and carbon dioxide concentrations of 5%, 10%, and 15%. The packaged samples were stored at a temperature of 10°C with a relative humidity of 75-85% for 28 days. Regardless of the variety used, the samples stored with 1-2% oxygen and 5% carbon dioxide exhibited the most effective retention of firmness, colour, total antioxidant capacity, total phenolic content, pyruvic acid, while minimizing weight loss and respiration rate throughout the 28-day storage period. These findings emphasize the importance of gas composition in MAP for maintaining the quality of garlic cloves during storage.

In a recent study, researchers investigated the impact of Hydroxypropyl methylcellulose (HPMC) with and without glycerol as an edible coating, combined with active modified atmosphere packaging (1% O_2 and 10% CO_2), on the storage of garlic cloves. The study involved packing the cloves in low-density polyethylene (LDPE) bags and storing them at 25°C for 12 days. The application of HPMC coating proved beneficial, as it prevented root formation and inhibited apparent microbial growth in fresh-cut garlic cloves, surpassing the results of uncoated and water-dipped samples. Although the HPMC coating did not significantly reduce weight loss, possibly due to its hydrophilic nature, no significant differences in firmness were observed among the treatments during storage. Moreover, the coated garlic cloves exhibited significantly higher gloss compared to the uncoated ones. Additionally, a higher concentration of CO2 was detected in the headspace of the modified atmosphere packaging of coated garlic cloves. These findings highlight the potential of edible coatings in extending the shelf life of garlic cloves by reducing rooting and enhancing gloss (Sothornvit R. *et al*., 2015).

The effect of UV-C treatment on the quality and functional properties of peeled garlic during storage was investigated in another study. The researchers found that UV-C-treated garlic cloves maintained their firmness better than the untreated controls throughout the storage period. After 15 days at room temperature, the UV-C-treated cloves exhibited lower hue values, indicating less yellow coloration compared to the controls. Furthermore, the UV-C treatment resulted in lower aerobic microbial populations in garlic cloves exposed to 2 kJ m^{-2} UV-C, both during room temperature storage for 15 days (6.78 log CFU vs. 6.10 log CFU) and refrigerated storage at 0°C for 30 days (with a one-log reduction in microbial population). Additionally, the UV-C-treated garlic cloves demonstrated higher levels of total polyphenols and flavonoids after 15 days of storage at 0°C, and the total flavonoid content remained significantly higher in UV-treated cloves than in the control cloves for up to 10 days at room temperature. These findings suggest that UV-C irradiation can effectively reduce microbial populations and maintain or increase antioxidant levels in peeled garlic cloves (Me-Hea Park *et al*., 2014).

A comprehensive study examined the impact of different packaging materials and storage conditions on the quality of minimally processed garlic. The study focused on two garlic varieties, PG 01 and PG 117, which were packed using LDPE, HDPE, PP, and plastic trays. The packed garlic cloves were stored under ambient and refrigerated conditions (3-5°C). The results revealed that garlic cloves could be stored in

LDPE films for up to 5 days at ambient temperature and over 15 days under refrigerated conditions. This suggests that LDPE packaging is suitable for maintaining the quality and extending the shelf life of minimally processed garlic (Sidhu *et al.*, 2012).

In another investigation, the potential of hot water dips (ranging from 45-60°C for 2.5-60 minutes) as a treatment to inhibit sprout and root growth in peeled or unpeeled garlic cloves was evaluated. The study focused on cloves where sprouts had begun internal development but had not yet emerged. Results showed that water dips at temperatures ≤50°C did not effectively reduce sprout and adventitious root growth in cloves stored at 10°C and over 95% relative humidity (RH). However, treatments at 55°C for 10 minutes demonstrated efficacy. Dips at 60°C inhibited sprout and root growth, with a 2.5-minute treatment proving both effective and non-injurious. Respiration rates of heat-treated garlic were higher than those of untreated cloves, and while the L* colour value (lightness) of peeled cloves sometimes decreased with heat treatment, chroma and hue remained unaffected. Notably, a 2.5-minute dip at 60°C was equally effective as a 1% O_2 + 10% CO_2 atmosphere in retarding sprout and root growth over a 6-month period at temperatures ranging from 0-1°C (Marita I. *et al.*, 2003).

The concept of modified atmosphere (MA) involves the alteration of atmospheric composition by either removing or adding specific gases, resulting in a different composition from the ambient air. Research has shown that the most effective modified atmospheres for maintaining the quality and extending the storage life of minimally processed products typically consist of an oxygen range of 2% to 8% and a carbon dioxide concentration of 5% to 15% (Cantwell *et al.*, 2001).

In relation to the packaging of garlic cloves, modified atmosphere packaging (MAP) has demonstrated significant benefits. A study compared the use of MAP with control packages and found that the modified atmospheric packages effectively reduced the occurrence of brown spotty disorder and decay, outperforming the control packages. The control packages, on the other hand, resulted in higher weight loss but exhibited lower levels of sprouting and rooting. Among the experimental conditions, LDPE packages with a modified atmosphere consisting of 0% oxygen and 24% carbon dioxide showed the best results in reducing colour change and suppressing sprouting and rooting of the garlic cloves (Jun soo *et al.*, 1999).

Another study focused on evaluating the effect of modified atmosphere packaging (MAP) on the marketing quality of a garlic variety called 'Namdo' under different shelf temperature conditions. The garlic cloves were cold-stored for duration of 8 months, peeled, and then packed in low-density polyethylene film zipper bags with a modified atmosphere. The findings revealed that MAP, in combination with low temperatures, significantly reduced the occurrence of brown spot disorder. Moreover, sprouting, internal leaf growth, and rooting of the garlic cloves were effectively inhibited when stored at 0°C, regardless of whether MAP was applied or not. Specifically, the rate of rooting was observed to be 56% at a shelf temperature of 7°C, while it remained at only 0.7-1.3% under ambient shelf temperatures ranging from 18-23°C (Park *et al.*, 1999).

Conclusion

Based on the existing literature, it has been consistently demonstrated that both low temperature storage and modified atmospheric packaging play significant roles in preserving the quality of peeled garlic cloves. To further extend the shelf life of these cloves, a combination of edible coating materials (such as HPMC, Chitosan, and natural plant-gel) with modified atmospheric packaging has proven effective. Additionally, alternative preservation methods such as heat treatment, including hot water dips and gamma ray application, have shown promise in reducing sprout development. These treatments have yielded the most favourable outcomes when samples were stored under low temperature conditions (ranging from 0°C to 5°C) with a modified atmospheric packaging concentration of 0-1% oxygen (O_2) and 20-25% carbon dioxide (CO_2).

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