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Fruit preservation packaging technology based on air adjustment packaging method

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Abstract

Fresh vegetables and fruits need oxygen (O_2) to carry out their metabolic activities, particularly respiration. The procedure where the actively respiring commodity is sealed in film packages made of polymer to change the CO_2 and O_2 levels of concentration inside the package environment required to increase shelf-life and preserve freshness is referred to as modified atmosphere packaging (MAP). To affect the product's metabolism being packaged or the activity of organisms that cause degradation to extend the time of preservation, it is frequently desired to create an environment high in CO_2 and low in O_2. MAP changes the environment and increases moisture preservation that has a bigger impact on quality preservation. Moreover, packing separates the product from the surrounding environment, assisting in the creation of circumstances that, if not hygienic, at the very least minimize exposure to infections and pollutants, as well as physiological damage. MAP is a dynamic mechanism that occurs concurrently throughout permeation and respiration. As a result, MAP design necessitates the assessment of the product's intrinsic features, such as film permeability, optimal O_2 and CO_2 gas concentrations, and respiration rate. The goal of MAP design is to specify parameters that will provide the greatest feasible environment within the package for increasing the product's shelf-life in the quickest possible time. This is accomplished by synchronizing the packed produce's respiration rate with O2 and CO2 gas penetration rate through the film. The current study contains a detailed discussion of all of these elements of MAP.

Keywords: MAP; oxygen; controlled atmosphere; carbon dioxide.

Practical Application: Fruit preservation packaging technology.

1 Introduction

Vegetable and fruits output in the globe has increased to 1.4 billion tons. Every year, the world produces about 500 MT of fruits and 900 MT of vegetables (Panghal et al., 2018; Ricciardi et al., 2018). Vegetable output has been steadily growing, and fruit production has followed suit. Between 1980 and 2004, the average annual growth of fruits (2.2 percent p.a.) was nearly half that of veggies (4.2 percent p.a.). External trade goods account for around 10% of all fruits cultivated worldwide; this proportion is much lower for vegetables, at about 3-4 percent (Balali et al., 2020). The vegetable and fruits industry is perhaps one of the fastest expanding of all agricultural sectors during the previous quarter-century (1980-2004). The global intake of vegetables and fruits grew by 4.5 percent each year on average. This was larger than the worldwide rate of population growth, implying that global per capita vegetable and fruits consumption has risen as well (Anderson & Birner, 2020; Saha & Eckelman, 2017). The World Health Organization (WHO) claims that vegetable and fruits intake need to be at least 400 g per capita per day to avoid chronic illnesses such as obesity, diabetes, cancer, heart disease, and around half of the nations have attained this level (Banwat et al., 2012; Food Agriculture Organization, 2005; Yazew & Daba, 2020). Fruit and vegetable post-harvest losses, on the other hand, continue to be considerable. The yearly loss of fruits and vegetables due to insufficient equipment and inappropriate handling, packing, and preservation technologies is estimated to be between 25 and 40 percent of total production (Hailu & Derbew, 2015).

Vegetables and fruits are significant sources of minerals, vitamins, dietary fibers, organic acid, protein, glucose, and they are regarded as an essential component of the nutritional system (Yahia et al., 2019). As a result, vegetables and fruits are always in high demand. On the other hand, vegetables and fruits are perishable goods with a short shelf life and lose their freshness quickly after harvesting (Septembre-Malaterre et al., 2018). Due to substantial loss of post-harvesting and the market need for fresh fruits and vegetables in even brief times, many storage technologies have been developed to keep the goods in pristine condition for longer periods of time. The safeguarding of vegetables and fruits against physical harm and microbiological contamination maintains the commodities in good condition; nevertheless, the products' shelf-life would not extend beyond

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their natural season (Elik et al., 2019; Kereth et al., 2013). This is due to the fact that vegetables and fruits are still alive, and their metabolism proceeds after harvest. However, because their metabolism differs from that of the parent plant flourishing in its natural habitat, they suffer pathological and physiological degradation and losses (Gardas et al., 2017). Any change in the food's quality, wholesomeness, edibility, or availability that prohibits it from being consumed by people is referred to as a loss. Psychological and physiological, physical, mechanical, biochemical reactions, chemical, microbiological, and biological factors might all play a role in losses (Gutierrez, 2018). The majority of perishable crop losses are caused by physiological, mechanical, and microbiological causes. Harvesting, preparing, preserving, processing, storing, and moving are all possible points where losses might occur between the time the food is produced or gathered and the time it is consumed (Irtwange, 2006; Yahia & Carrillo-Lopez, 2018). Respiration is the primary catabolic process that contributes to subsequent degradation, senescence, and natural ripening. Minimizing mechanical injuries, harvesting at optimum maturity through adequate sanitary procedures, and supplying the optimal humidity and temperature throughout all marketing steps are the main components in increasing the post-harvest life of fresh vegetables and fruits and preserving quality (Bruinsma & Paull, 1984; Santos et al., 2019; Kochevenko et al., 2012). Additional variables involve changing the levels of ethylene (C_2H_4), carbon dioxide (CO_2), and oxygen (O_2) in the environment surrounding the product to levels not found in the air (Flores-Cortez et al., 2018). MA storage and controlled atmosphere (CA) systems are terms adapted to describe this type of storage. In terms of preserving particular amounts of O_2, CO_2, as well as other gases, CA indicates a higher degree of accuracy than MA (Bahar & Lichter, 2018; Ma et al., 2019; Thompson et al., 2018).

2 Modified Atmosphere Packaging (MAP)

2.1 MAP's background

In 1927, MAP was initially discovered as a way to prolong the shelf life of apples by keeping them in atmospheres with lower levels of oxygen and higher levels of carbon dioxide (Zhang et al., 2015). It was first employed as MA storage in the 1930s to carry beef and fruits in ship holds by raising CO_2 concentrations for long-distance transit, and it has been found to increase storage life by a hundred percent. Yet, it wasn't until the early 1970s in Europe that the technology was commercialized for retail packaging (Bailén et al., 2006; Church & Parsons, 1995). The absence of constant control of O_2 levels in the package was the major technical constraint of MAP application in early experiments (Davies, 1995; Kader et al., 1989). Polymer kinds and characteristics have expanded ever since, allowing for a greater variety of clarity, printability, flexibility, tensile strength, and gas permeability. Consequently, MA packaging solutions for a variety of commodities have been created. In 1979, Spenser and Marks launched MAP for meat in the United Kingdom, and the product's popularity led to the launch of MAP for cooked shellfish, sliced cooked meats, fish, and bacon many years later (Priyadarshi et al., 2020). Various food producers and supermarket chains followed suit resulting in a significant rise in the availability of MAP food products, indicating rising customer demand for foods with extended shelf lives and fewer preservatives.

2.2 Principles of MAP

The natural interaction between two processes, the product's respiration and the passage of gases via the packaging, results in an environment poorer in O_2 and richer in CO_2. It depends on the properties of the product and the packaging film. This environment has the ability to physiological changes, such as oxidation, degradation, compositional alterations, softening, ripening, C_2H_4 sensitivity and production, and lower respiration rates. The exposure of products to the environment created in a package as a result of the interaction of the external atmosphere, the package, and the product is known as MAP (Opara et al., 2019). Air or a gas mixture might be used as the starting atmosphere. Before the package is sealed, several additives that could have an impact on the environment may be added (Moradinezhad et al., 2020).

Fresh food is packaged in films made of polymers, resulting in a commodity-generated MA. The gas diffusion properties of the product, commodity respiration rate, film permeability, as well as the atmospheric composition inside the package, starting free volume, surface area, the weight of the product all influence atmospheric modification (Yun et al., 2017). The permeability of the film is affected by air movement around the package, relative humidity, and temperature. The temperature has an impact on the commodity's metabolism and, as a result, the rate at which it achieves the target MA (Jalali et al., 2017). All of these aspects must be taken into account when creating a computational model for determining the best film for each product.

2.3 MAP's objective

Designing a MAP has a certain aim in mind, to specify parameters that would provide the optimum environment for the long preservation of a specific product while reducing the time it takes to do it (Beaudry et al., 1992). To put it another way, MAP's primary objective is to accomplish the equilibrium levels of CO_2 and O_2 inside the package in the fastest time possible due to interactions of the external atmosphere, the package, and the produce; and that these concentrations are within the specified limits for the commodity's longest storage life feasible (Mangaraj & Goswami, 2009; Sousa-Gallagher & Mahajan, 2013). For preserving freshness and increasing the shelf-life of preserved commodities, the equilibrium concentration of CO_2 and O_2 established must be maintained constant during the storage duration. This may be accomplished by synchronizing the film penetration rate for CO_2 and O_2 to the packed produce's respiration rate. Because various goods behave differently and MA packages will be introduced to environmental changes, each package must be tailored to meet unique requirements (Corato, 2020; Yun et al., 2017). A poorly constructed MAP system might render a commodity useless or possibly reduce its storage life. The package will be of no use if the required environment is not quickly formed; if CO_2 and/or O_2 levels are not within the specified range, the commodity may undergo significant changes, reducing its storage life.

2.4 Applications of MAP

The most evident benefit of MAP in vegetables and fruits is the increased shelf life. The rate of all metabolism and the respiration rate are both reduced when the amount of accessible O_2 to the plant is reduced (Brody et al., 2010; Mahajan & Sousa-Gallagher, 2011). This causes prolonged senescence and ripening, which could be seen as prevention of discoloration, delayed softening, and chlorophyll retention. With prepped items, the extended shelf-life is most evident; this, along with the consumer's convenience of use, renders a MAP pack an appealing type of product display. MAP packs also cut down on the amount of water vapor wasted by the produce (Chattopadhyay et al., 2021; Floros & Matsos, 2005).

Fresh vegetables and fruits will continue to breathe despite being separated from their regular nutritional sources and the parent plant (Malkia & Etsouri, 2018). A product's rate of respiration can be assessed by either the rate of CO_2 generation or the rate of O_2 absorption under typical aerobic circumstances. A high rate of respiration is generally linked to a short shelf life (Awuchi et al., 2020). An equilibrium concentration of both gases is reached when the rate of CO_2 and O_2 transmission through the packing film equals the rate of product respiration. The product's film surface area accessible for the exchange of gases, fill weight, and respiration rate all contribute to the equilibrium value. Product damage, growing condition, and location produce variety, and storage temperature all impact the pace at which the product breathes (Badillo & Segura-Ponce, 2020).

Long-term storage of Chinese cabbage, cabbage, orange, sapota, potato, kiwi fruits, pears, and apple; momentary storage and/or transit of tomato, mushroom, guava, litchi, bananas, cherries, bush berries, strawberries, and other commodities; and retailing of some sliced or cut vegetables are some of the current applications of MAP technologies (Kargwal et al., 2020). MAP enables the ideal environment to be maintained during the whole post-harvest handling period, from cultivation to consumption.

3 The benefits and drawbacks of MAP

MAP's benefits and drawbacks have been well researched and are listed here (Kargwal et al., 2020).

3.1 Advantages

1. In underdeveloped nations, MAP has a significant benefit since it can be done inexpensively by hand, avoiding the exorbitant expense of new gear. Furthermore, due to the scarcity of chilled storage, the necessity for such a technology is considerably higher.
2. Labor, space, and equipment are better used, resulting in lower production and storage costs.
3. The benefits of high quality are passed on to the customer.
4. Reduce the amount of undesirable or low-quality food that is handled and distributed.
5. Excellent branding possibilities.
6. At the retail level, labor and waste are reduced.
7. It is feasible to expand the distribution region while lowering transportation expenses owing to fewer deliveries.
8. There is a possibility of centralized/semi-centralized packing.
9. Chemical preservatives are used sparingly in MAP.
10. The product has a better presentation and is clearly visible all around the package.
11. Increased shelf-life means that shop displays may be loaded into shelves less often.
12. Chilling injury is commonly treated.
13. Softening and compositional alterations are slowed by MAP.
14. It is common to reduce fungal growth and illness.
15. Color, wetness, tastes, and maturity retention are examples of quality benefits.
16. MAP helps to reduce pathological degeneration, disorder, and physiological damage.
17. In MAP, there is a reduction in shriveling, desiccation/water loss, and weight loss.
18. There is a ripening delay.
19. Reduced C_2H_4 sensitivity and production, browning degradation, yellowing, metabolic heat generation, moisture loss, and respiration rate all occur.
20. Increased CO_2 and reduced O_2 levels decrease the commodity's respiration rate, slow essential processes, and extend the time it takes to maintain post-harvest quality.
21. When compared to normal storage, freshness is preserved, and the shelf life is extended from several days to many weeks, thanks to MAP.

3.2 Disadvantages

1. Because the intrinsic characteristics of the commodity vary considerably depending on maturation stage, cultivation location, cultivar, etc., and the permeability of the films changes depending on the method, the manufacturing firm, etc., there is no specific standard for MA packaging.
2. The majority of the product does not yet have MAP technology.
3. Plastic films may be harmful to the environment if they are not properly recycled.
4. Due to the potential growth of anaerobic pathogenic flora, additional concerns to microbiological safety might arise.
5. Due to poor packing or temperature abuse, there is a risk of product spoiling.

6. In the packing line, there will be a need for extra machinery and labor.

4 Respiration rate

Even after harvest, the tissues of plants in fresh-cut produce respire and are still alive, gaining energy largely through respiration (Shapawi et al., 2021; Wilson et al., 2019). The process of respiration is catabolic, in which atmospheric O_2 is used to consume organic acids, proteins, lipids, and carbohydrates in plant tissue, resulting in the formation of different intermediate molecules, CO_2, metabolic energy, and water. High-energy bonds can be used to store the energy produced during respiration in compounds utilized by the cell in later biochemical processes and reactions, or it can be lost as heat (Charles et al., 2003; Mathooko, 1996; Varoquaux et al., 1999). Other metabolic processes utilize the organic compounds and energy generated during respiration to keep the commodity healthy. Vital heat is the heat that is produced when breathing, and it contributes to the load of refrigeration that must be included in the storage room design. From a biochemist's point of view, Respiration is the disintegration of complicated substrate molecules by oxidation found in plant cells, like organic acids, sugars, and starch, into simple molecules like water and CO_2 (Giné-Bordonaba et al., 2017). Aerobic respiration is described as the decomposition of organic resources (carbohydrate) into simple molecules oxidatively, like CO_2, as given by the equation: energy (heat)+ $6H_2O+6O_{26}CO_2+C_6H_{12}O_6$ (Rocculi et al., 2006). The loss of stored food reserves in the commodity during the respiration process hastens the onset of senescence because the resources that supply energy are depleted (Saltveit, 2019). Furthermore, the consumption of substrates in respiration can lead to a reduction in the tissue's food reserves and a reduction in food value and quality for the consumer.

Table 1 shows how the commodities are categorized based on their respiration rates. Table 2 provides an overview of fruit respiration and C_2H_4 generation rates at different temperatures. Fruits' respiration rates rise while they are shredded, sliced, chopped, or otherwise processed. This is most likely due to the expanded surface area revealed to the environment after cutting, which allows O2 to permeate more quickly into the inner cells and the enhanced metabolic activity of damaged cells.

The rate of respiration varies across and among products. Broccoli and asparagus, for example, have relatively high respiration rates because they have floral or vegetative meristems. Vegetables consist of a wide range of plant parts (leaves, stems, sprouts, fruits, bulbs, roots, etc.) with varying metabolism and, as a result, varying rates of respiration (Fonseca et al., 2002). Even various kinds of the same product might have varying rates of respiration. The rate of respiration of plant organs generally decreases as they develop (González-Buesa & Salvador, 2019; Lufu et al., 2019). Commodities gathered throughout active growth, such as many young fruits and vegetables, have high rates of respiration (Chang et al., 2017). The rates of storage organs, latent buds, and mature fruits are all relatively low. The rate of respiration slows in storage organs and non-climacteric fruits after harvest but accelerates in immature fruits and vegetative tissues. The fast decrease is thought to be due to a lack of respirable substrates, which are generally few in such tissues (Alós et al., 2019; Shakya & Lal, 2018; Yang & Pratt, 2019). During the ripening of climacteric fruit, there is a rapid and frequently dramatic increase in respiration, a notable exception to the typical reduction in respiration following harvest (Figure 1). This long-studied increase usually has four different phases (Thompson et al., 2019):

1) post-climacteric decline.

2) climacteric peak,

3) climacteric rise,

4) pre-climacteric minimum.

Table 1. Agricultural products are classified based on their ethylene generation and respiration rates.

Class	Ethylene production rates	Ranges at 20 °C ($\mu l\ C_2H_4$/kg-hr)	Respiration rates	Ranges at 5 °C (mg CO_2/kg-hr)
	Commodities		Commodities	
Extremely high		> 200	Sweet corn, spinach, peas, parsley, mushroom, raspberry, broccoli, asparagus	> 60
Very high	Cherimoya, mammee apple, passion fruit, sapota	> 100 < 200	Artichoke, bean sprouts, broccoli, snap beans, green onion, cut flower, brussels sprouts	40 - 60
High	Apple, apricot, avocado, cantaloupe, feijoa, kiwifruit (ripe), nectarine, papaya, peach, pear, plum	10.00 - 100.00	Strawberry, litchi, blackberry, raspberry avocado, cauliflower, lima bean	20 - 40
Moderate	Banana, fig, guava, honeydew, melon, mango, plantain, tomato	1.0 - 10.00	Apricot, banana, cabbage, sapota, mango, guava, tomato, plum, pepper, pear, peach, olive, nectarine, lettuce, gooseberry, fig, cucumber, cherry, carrot, cantaloupe	10 - 20
Low	Blueberry, cranberry, cucumber, eggplant, okra, olive, pepper, persimmon, pineapple, pumpkin, raspberry, tamarillo, watermelon	0.1 - 1.00	Apple, celery, citrus fruits, garlic, grape, kiwifruit, onion, persimmon, pineapple, potato, sweet potato, watermelon	5 - 10
Very low	Artichoke, asparagus, cauliflower, most cut flowers, potato, root vegetables, leafy vegetables, pomegranate, strawberry, jujube, grape, citrus, cherry	< 0.1	Dates, nuts, dried fruits, and vegetables	< 5

Sources: Church & Parsons, 1995; Irtwange, 2006; Saltveit, 2005.

Table 2. At various temperatures, the ethylene production and rates of respiration of several fruits are summarized.

Commodity	Respiration rate (mg CO2/kg-hr) temperature of						C_2H_4 production
	0 °C	5 °C	10 °C	15 °C	20 °C	25 °C	(µl C_2H_4/kg-hr)
Apple Fall	3	6	9	15	30	na	Varies greatly
Summer	5	8	17	25	31	na	Varies greatly
Raspberry	17[6]	23	35	42	125	na	12.0 (20 °C)
Grape, Muscadine	10[6]	13	na	na	51	na	< 0.1 (20 °C)
Artichoke	30	43	71	110	193	na	< 0.1
Blackberry	19	36	62	75	115	na	Varies; 0.1 - 2.0
Strawberry	16	na	75	na	150	na	< 0.1 (20 °C)
Cherry	8	22	28	46	65	na	< 0.1 (0°C)
Apricot	6	na	16	na	40	na	< 0.1 (0°C)
Blueberry	6	11	29	48	70	101	Varies; 0.5 - 10.0
Asian pear	5	na	na	na	25	na	Varies greatly
Beets	5	11	18	31	60	na	< 0.1 (0 °C)
Nectarine (ripe)	5	na	20	na	87	na	5.0 (0 °C)
Peach (ripe)	5	na	20	na	87	na	5.0 (0 °C)
Orange	4	6	8	18	28	na	< 0.1 (20 °C)
Grape, American	3	5	8	16	33	39	< 0.1 (20 °C)
Grape, Table	3	7	13	na	27	na	< 0.1 (20 °C)
Kiwifruit (ripe)	3	6	12	na	19	na	75
Plum (ripe)	3	nd	10	na	20	na	< 5.0 (0 °C)
Avocado	na	35	105	na	190	na	> 100 (ripe; 20 °C)
Banana (ripe)	na	na	80	140[3]	280	na	5.0 (15 °C)
Grapefruit	na	na	na	< 10	na	na	< 0.1 (20 °C)
Guava	na	na	34	na	74	na	10 (20 °C)
Litchi	na	13	24	na	60	102	Very low
Mamey apple	na	na	na	na	na	35	400.0 (27 °C)
Mandarin (tangerine)	na	6	8	16	25	na	< 0.1 (20 °C)
Mango	na	16	35	58	113	na	1.5 (20 °C)
Papaya (ripe)	na	5	na	19	80	na	8.0
Passion fruit	na	44	59	141	262	na	280.0 (20 °C)
Pineapple	na	2	6	13	24	na	< 1.0 (20 °C)
Pomegranate	na	6	12	na	24	39	< 0.1 (10 °C)
Sapote	na	na	na	na	na	na	< 100 (20 °C)
Tomato	na	na	15	22	35	43	10.0 (20 °C)

na = data not available, very low is considered to be < 0.05 µL C2H4/kg-hr; Sources: Blanke & Bower, 1991; Obando et al., 2007; Saltveit, 2005.

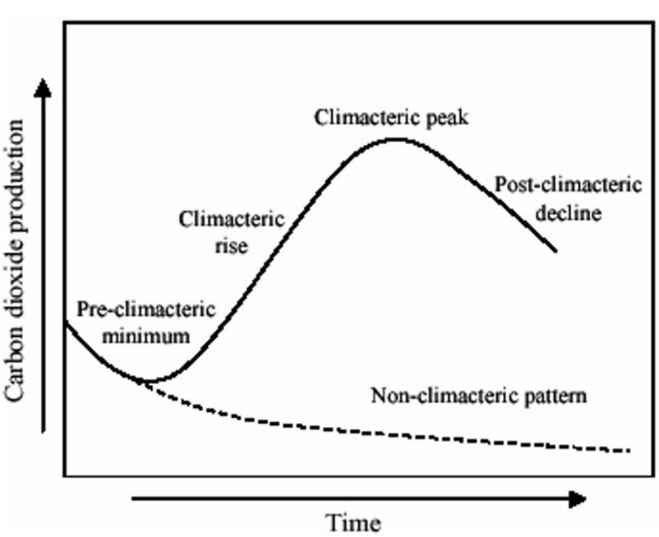

Figure 1. The pattern of climacteric respiration in ripening fruit.

Non-climacteric products, on average, have greater rates of respiration in the initial phases of growth, which gradually decrease as they mature. Climacteric commodity rates of respiration are likewise high early in development and decrease until a surge corresponds with senescence or ripening (Figure 1) (Alam et al., 2021; Gupta et al., 2021).

5 Conclusion

Vegetables and fruits are preserved using MAP as a complement to low-temperature storage. It's mostly utilized to slow down respiration and slow down the process of ripening, giving the host more infection tolerance. MA is commercially outstanding for storing fresh-cut vegetables and fruits, pears, and apples and extremely fragile and high-value products, including mushroom, capsicum, litchi, strawberries, raspberry, fig, cherry and other perishable and high-value commodities. For most vegetables and fruits, a small gain in quality and storage life provided by MA preservation is insufficient to justify the increased expense of commercializing MA technology. The impact of MA differs for the same species grown in various locations, under different cultural methods, or in various seasons, which is a significant challenge in the market deployment of MA in vegetables and fruits. As a result, trial-and-error research must be carried out to find the best environment for each cultivar in a certain location and season. In wealthy countries, films with any required permeability to CO_2, O_2, and water vapor may be packaged; however, this is not the case in poor countries. Models of the rate of respiration and gas permeability of fresh vegetables and fruits should be created. It is feasible to maintain an optimal environment for prolonging the shelf-life and proper storage of goods using the model and crucial design of the MAP system. Because vegetables and fruits are more susceptible to external factors, precise MAP design is essential for achieving the excellent quality of the product, and the creation of models for various vegetables and fruits is a must. To render this technique economically feasible, more research on combining active packaging with MAP is required. Economically viable C_2H_4 removal methods are currently unavailable. C_2H_4-absorbing compounds should be investigated in active packaging. With promising results, MAP and similar technology may be used to selectively handle fresh vegetables and fruits after harvest. Fresh produce sellers and processors need to commercialize the technology. In underdeveloped nations, MAP and associated technological study are also required for indigenous crops grown under local circumstances.

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