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The Role of Modified Atmosphere Packaging in Reducing Postharvest Losses and Extending the Self Life of Fresh Produce Fruits, Vegetables, Fish and Poultry

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Abstract:- Modified Atmosphere Storage (MAS) and Packaging (MAP) are advanced preservation technologies widely utilized in the post-harvest handling of fruits, vegetables, and poultry products to extend shelf life, maintain quality, and reduce spoilage. These methods involve altering the atmospheric composition within storage or packaging environments, typically by reducing oxygen levels and increasing carbon dioxide concentrations. The three main gases utilized in food processing are carbon dioxide (CO_2), nitrogen (N_2), and oxygen (O_2). The majority of fresh fruits, vegetables, and food items are made using various combinations of two or three of these gases, depending on what the demands of the particular product are. Generally, a 30–60% CO_2 split is utilized for non-respiring items, where microbial growth is the primary spoiling characteristic. The remaining amount can either be pure N2 (for foods sensitive to O_2) or a combination of N_2 and O_2. In order to minimize the respiration rate, around 5% CO_2 and O_2 are often employed for respiring products gas level, with N_2 making up the remaining amount. This creates conditions that slow down metabolic activities, microbial growth, and oxidative reactions. For fruits and vegetables, MAS and MAP help in delaying ripening, reducing respiration rates, and maintaining texture and nutritional value. In the case of poultry products, these technologies are crucial in minimizing microbial contamination, preventing spoilage, and maintaining sensory attributes such as colour, flavour, and tenderness.

Keywords:- *Carbon Dioxide, Oxygen, Nitrogen, Respiration, Fresh Food Products, Temperature, Self-Life.*

I. INTRODUCTION

According to the recent FAO report, 50% of agricultural products are destroyed because of the absence of packaging. The causes of this loss are bad weather, physical, chemical and microbiological deteriorations. Progress in the packaging of foodstuffs will prove crucial over the next few years mainly because of new consumer patterns, demand creation and world population growth which is estimated to reach 15 billion by 2025. The effectiveness of MAS and MAP is influenced by factors such as the type of product, storage temperature, and specific gas concentrations. Recent advancements include the development of biodegradable packaging materials and intelligent packaging systems that monitor and adjust gas levels in real-time. This review paper aims to explore the principles, applications, and benefits of MAS and MAP in preserving fruits, vegetables, and poultry products. It also discusses current challenges, technological innovations, and future prospects in this field, providing a comprehensive overview of the state-of-the-art in modified atmosphere technologies.

II. PRINCIPLE

Modified Atmosphere Packaging (MAP) is a technology used to extend the shelf life of perishable food products by altering the atmosphere inside the packaging. The principle behind MAP involves replacing the air inside the packaging with a specific gas mixture that slows down the spoilage processes. Here's how it works:

- Gas Composition: The typical air composition is about 78% nitrogen, 21% oxygen, and 1% other gases (including carbon dioxide). In MAP, this natural air mixture is altered to contain different proportions of gases, most commonly nitrogen (N_2), carbon dioxide (CO_2), and sometimes a small amount of oxygen (O2) [12].
- Slowing Down Microbial Growth: Microorganisms, such as bacteria and fungi, require oxygen to grow. By reducing the oxygen level in the packaging and increasing the levels of CO_2, the growth of these spoilage organisms is slowed down. This helps in extending the freshness and safety of the food.
- Reducing Oxidation: Many foods, especially those high in fats and oils, can undergo oxidative spoilage, leading to rancidity and off-flavours. Lower oxygen levels reduce the rate of oxidation, thus maintaining the quality of the product.
- Preventing Moisture Loss: MAP can help in maintaining the moisture content of the food. For example, in the case of fresh produce, a modified atmosphere with an optimal balance of gases can reduce dehydration and maintain the crispness of vegetables and fruits.

- Packaging Materials: The success of MAP depends on the packaging material used. It must have suitable barrier properties to maintain the modified atmosphere inside the package. Common materials include certain types of plastics and foils that are impermeable to gases [20].
- Sealing Techniques: The packaging must be sealed properly to maintain the modified atmosphere. Heat sealing, vacuum sealing, and other advanced sealing techniques are often employed to ensure the integrity of the package.

III. MAP GASES

Three major gases used in the MAP of fresh produce foods like fruits, vegetable or any poultry products are oxygen (O_2), nitrogen (N_2) and carbon dioxide (CO_2). To increase the shelf life of a particular food product, various combinations of two or three of these gases are utilized. When microbial growth is the primary cause of deterioration in non-respiring items, 30–60% of CO_2 is typically utilized. The remaining space is then filled with either pure N_2 (for food that is sensitive to O_2) or mixtures of N_2 and O_2. The packing of food products that need respiration employs a minimum amount of O_2 and CO_2, with the remaining portion being filled with N_2 to minimize the pace of respiration. Other gases include argon, nitrous oxide, ethylene oxide, helium, neon, and carbon monoxide, which are also utilized to extend the self-life of the gas and preserve the red colour of red meat. Ethanol vapour and propylene oxide also used for self-life extension of bakery products [14].

A. Carbon Dioxide (CO2)

CO_2 is the one of the most important gases in the MAP of foods, due to its bacteriostatic (prevent the growth of the bacteria) and fungistatic (prevent the growth of the fungi) properties. The growth of several spoilage bacteria, which cause food degradation, is blocked by it. Moreover, the inhibition rate increases as the quantity of CO_2 in the specific environment rises. CO_2 is very soluble in water and fat, and its solubility rises significantly as the temperature drops. 3.38g of CO_2/kg H_2O is soluble in water at 0°C and 1 atm pressure; at 20°C, its solubility drops to 1.73g of CO_2/kg H_2O. As a result, the temperature at which the gas is stored always affects its efficacy. Therefore, the effectiveness of the gas is always depending on the storage temperature. So, it resulting in increased inhibition of bacterial growth as the temperature of the storage is decreased. The solubility of the CO_2 leads to dissolved CO_2 in the food products;

$$CO_2\,(g) + H_2O \leftrightarrow HCO_3^- + H^+ \leftrightarrow CO_3^{2-} + 2H^+$$

- Inhibition of Microbial Growth: CO_2 has antimicrobial properties. High concentrations of CO_2 (usually between 20% to 60%) can inhibit the growth of spoilage bacteria and Molds. It is particularly effective against aerobic microorganisms, which require oxygen to grow. By reducing the oxygen levels and increasing CO_2 levels, MAP creates an environment that is less conducive to microbial proliferation.
- Reduction of Respiration Rate: For fresh produce, such as fruits and vegetables, CO_2 helps to reduce the respiration rate. Respiration is the process by which produce consumes oxygen and releases CO_2, water, and heat. High levels of CO_2 slow down this process, which in turn slows down ripening and aging, thereby extending shelf life [18].
- Prevention of Oxidation: CO_2 helps in reducing the oxidation of fats and oils in food products. Oxidation can lead to rancidity and spoilage, particularly in products like meats and dairy. By displacing oxygen within the package, CO_2 helps to prevent these oxidative reactions.
- Maintaining Product Quality: CO_2 helps in maintaining the sensory and nutritional quality of the food product. By slowing down microbial growth and oxidation, the colour, flavour, texture, and nutritional value of the food are better preserved.
- Regulation of pH: CO_2 can dissolve in water present in food, forming carbonic acid. This slight acidification can further inhibit microbial growth and enzyme activity, contributing to the preservation of the food product.
- Control of Package Volume: In some cases, the presence of CO_2 can cause slight swelling of the package, which can help in protecting delicate products from mechanical damage [28].

B. Nitrogen (N2)

Reduction of Oxidation and inhabitation of microbial growth: N_2 is an inert gas and does not react with food components. By displacing oxygen, it helps to reduce oxidation reactions that can lead to spoilage, off-flavours, and rancidity, especially in fats and oils. Many spoilage microorganisms and pathogens require oxygen to grow. By reducing the oxygen concentration, N_2 helps to inhibit the growth of these aerobic microorganisms. This inhibition of microbial growth contributes significantly to extending the shelf life of food products. N_2 is used to balance the mixture of gases inside the package. It acts as a filler gas, adjusting the levels of O_2 and CO_2 to optimal concentrations for different types of food products. This balance is crucial for maintaining food quality and extending shelf life. In products like meats, reducing the oxygen level helps to prevent oxidative discoloration, preserving the desirable red colour. N_2 helps achieve and maintain the low oxygen levels necessary for this purpose [25].

- Displacement of Oxygen (O_2): One of the primary roles of N_2 in MAP is to displace oxygen. Oxygen can promote the growth of aerobic bacteria and lead to oxidation, which causes spoilage and rancidity in food products. By reducing the oxygen levels, N_2 helps in slowing down these degradation processes.
- Maintaining Product Freshness: N_2 is an inert gas, meaning it does not react with the food products. This characteristic helps in maintaining the freshness, taste, and nutritional quality of the food by preventing oxidative reactions.

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- Preventing Moisture Loss: By creating a dry environment inside the packaging, N_2 helps in preventing moisture loss from the product, which is particularly important for products like baked goods and dried fruits.
- Providing a Cushioning Effect: N_2 also provides a cushioning effect, protecting delicate products from mechanical damage during transportation and handling. This is particularly useful for products like potato chips, which can easily break.
- Slowing Down Respiration in Fresh Produce: For fresh fruits and vegetables, N_2 helps in slowing down the respiration rate by reducing the levels of oxygen, thereby extending their shelf life. This is crucial for maintaining the colour, texture, and flavour of fresh produce [30].
- Enhancing Product Safety: By inhibiting the growth of aerobic spoilage organisms and pathogens, N_2 contributes to enhancing the overall safety of the packaged products [33].

- ✓ Fresh Produce: In fruits and vegetables, N_2 helps to slow down the respiration rate and delay ripening and spoilage.
- ✓ Meat and Poultry: N_2 is used to reduce oxidative rancidity and inhibit the growth of aerobic bacteria.
- ✓ Bakery Products: For products prone to staling, N_2 helps to maintain freshness by reducing oxygen-induced degradation.
- ✓ Snack Foods: Nitrogen helps to prevent oxidation and rancidity in products like chips and nuts, which contain fats and oils.
- ✓ Meat and Poultry: Reducing oxygen levels to slow down the growth of spoilage bacteria and prevent discoloration.
- ✓ Dairy Products: Preventing oxidation and maintaining flavour and texture.
- ✓ Snacks: Providing a cushion to prevent breakage and maintaining crispness.
- ✓ Seafood: Preventing oxidation and maintaining freshness [5]

C. Oxygen (O_2)

- Inhibition of Anaerobic Bacteria: Oxygen can inhibit the growth of anaerobic bacteria, which thrive in low-oxygen environments. By maintaining a certain level of O_2, MAP can help prevent spoilage caused by these bacteria. This is particularly important for meat and seafood, where anaerobic bacteria like Clostridium botulinum can cause foodborne illnesses.
- Colour Preservation: In the packaging of fresh meat, oxygen helps maintain the desirable red colour. Myoglobin, a protein in meat, reacts with oxygen to form oxymyoglobin, which gives meat its bright red appearance. A high level of O_2 (typically around 70-80%) is often used in MAP for red meats to retain this appealing colour.
- Respiration of Fresh Produce: Fresh fruits and vegetables continue to respire after harvesting, consuming oxygen and producing carbon dioxide. A controlled level of O_2 in the packaging can help manage the respiration rate, delaying ripening and senescence. Typically, lower levels of O_2 (around 2-5%) are used for fresh produce to slow down respiration without causing anaerobic conditions.
- Shelf-Life Extension: The appropriate balance of oxygen and other gases (like nitrogen and carbon dioxide) can significantly extend the shelf life of various foods. For example, higher O_2 levels in MAP can reduce the growth of spoilage organisms and oxidative rancidity in high-fat foods, while low O_2 levels can slow down the metabolism of fresh produce [28].
- Quality and Safety: Maintaining the correct oxygen levels in MAP ensures the quality and safety of food products. It helps in preserving texture, flavour, and nutritional value while preventing the growth of pathogenic microorganisms.

- ✓ High O_2 levels (70-80%): Used for fresh red meats to maintain colour and inhibit anaerobic bacteria.
- ✓ Low O_2 levels (2-5%): Used for fresh produce to slow respiration and extend shelf life.
- ✓ Controlled O_2 levels: Used to balance the needs for colour retention, spoilage prevention, and extended shelf life across different types of food.

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IV. COMPARISON BETWEEN TRADITIONAL STORAGE AND MODIFIED ATMOSPHERE STORAGE

A. During the Traditional Storage Processes the Quality of Food Material will Decrease with Respect to Time by the Environmental Effects

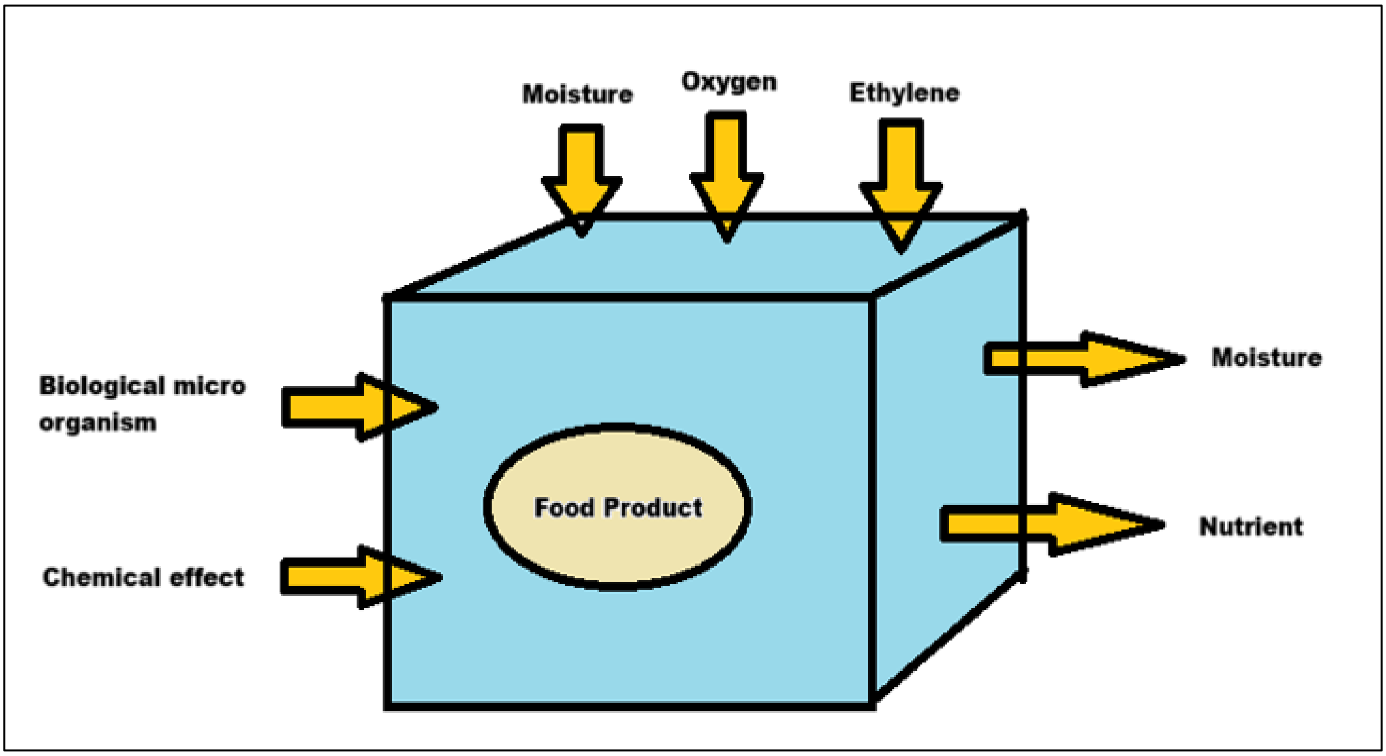

Fig 1: An Illustration of Potential Interactions between Food, Packaging and Environment Around

B. Food Products during the Modern Modified Atmosphere Packaging

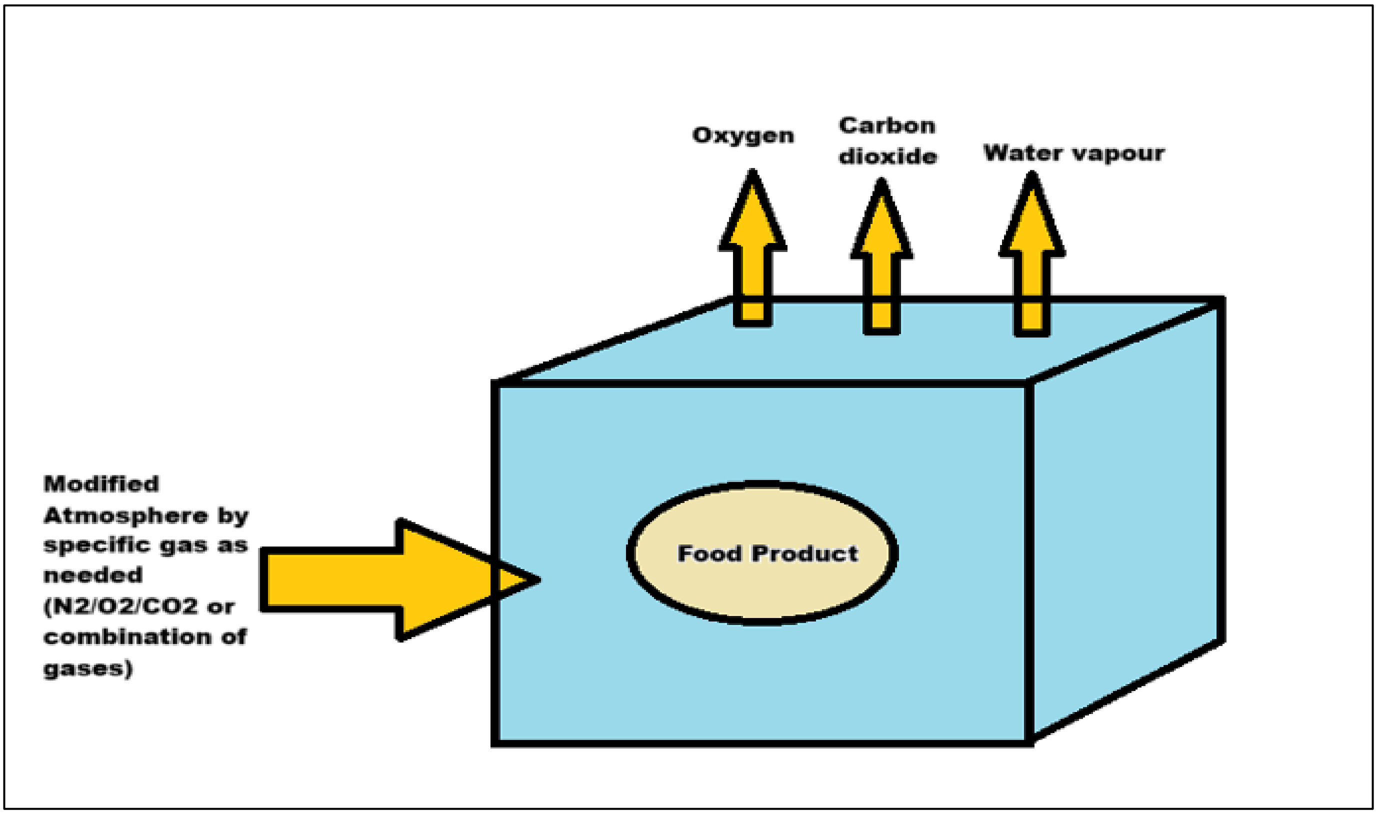

Fig 2: A Storage Condition of Food in Modified Atmosphere Packaging

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V. DIFFERENT MODIFIED GAS COMPOSITION FOR DIFFERENT FOOD PRODUCTS

A. Gas Composition in MAP Technology on Fresh Fruits [6].

Table 1: Gas Composition in MAP Technology on Fresh Fruits [6].

Product		Modified Atmosphere (%)			Estimated Shelf Life (Days
		N2	O2	CO2	
Fruit	Temperature(°C)				
Apple	0-4	92	1-2	1-3	50
Avocado	0-1	85	2-5	3-10	30
Banana	10-12	91	2-5	2-5	49
Grape	0-2	95	2-5	3-1	45
Mango	0-5	85	3-7	5-8	28
Orange	0-5	85	5-10	0-5	16
Papaya	7-12	85	2-5	5-8	25
Strawberry	<5	70	5-10	15-20	40
Pineapple	<5	85	50	50	7
Guava	<10	93	2-5	2-5	35
Lemon	0-5	85	5-10	0-10	15

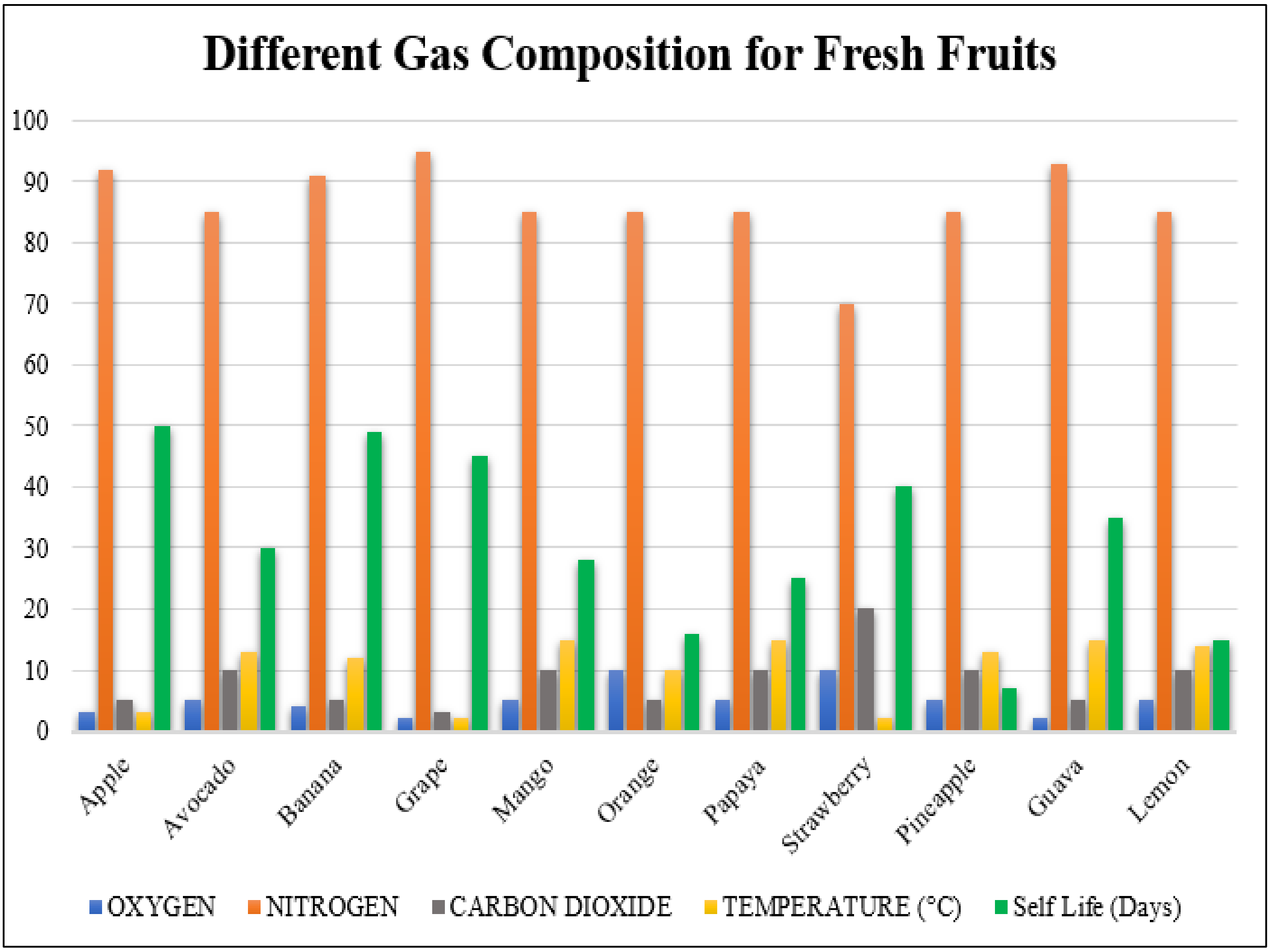

Fig 3: Different Gas Composition for Fresh Fruits

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B. Gas Composition in MAP Technology on Fresh Vegetables [2].

Table 2: Gas Composition in MAP Technology on Fresh Vegetables

Product		Modified Atmosphere (%)			Estimated Shelf Life (Days
Vegetables	Temperature(°C)	N2	O2	CO2	
Broccoli	3	88	2	10	60
Cabbage	5	90	3	7	90
Carrot	5	92	3	5	60
Cauliflower	2	93	2	5	45
Corn (sweet)	5	86	4	10	48
Cucumber	8	95	3	2	40
Mushroom	3	80	5	15	70
Spinach	3	62	18	20	40
Tomato	15	92	5	3	45
Potato	6	92	3	5	90

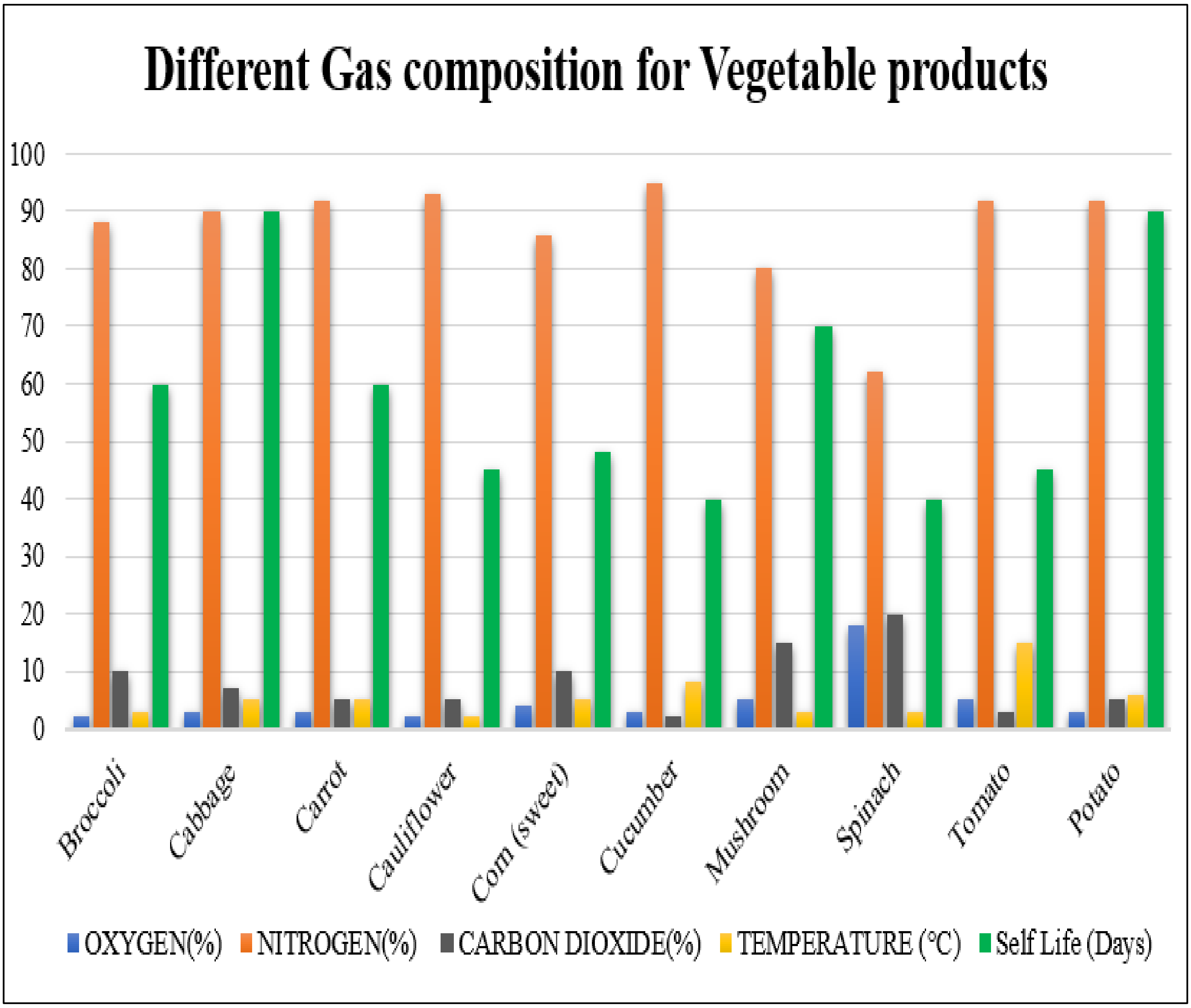

Fig 4: Different Gas Composition for Vegetables Products

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C. Gas Composition in MAP Technology on Fresh Raw Meat Product [2].

Table 3: Gas Composition in MAP Technology on Fresh Raw Meat Produc

Product		**Modified Atmosphere (%)**			**Estimated Shelf Life (Days**
Meat	**Temperature(°C)**	**N2**	**O2**	**CO2**	
Pork	3	5-10	40-70	20-30	10
Beef ham	2	40	00	60	12
Fresh beef	1	10	70	20	8
Chicken breast	2	5	65	30	15
Red meat	2	1-5	40-80	15-30	8
Poultry	2	70-80	00	20-30	21

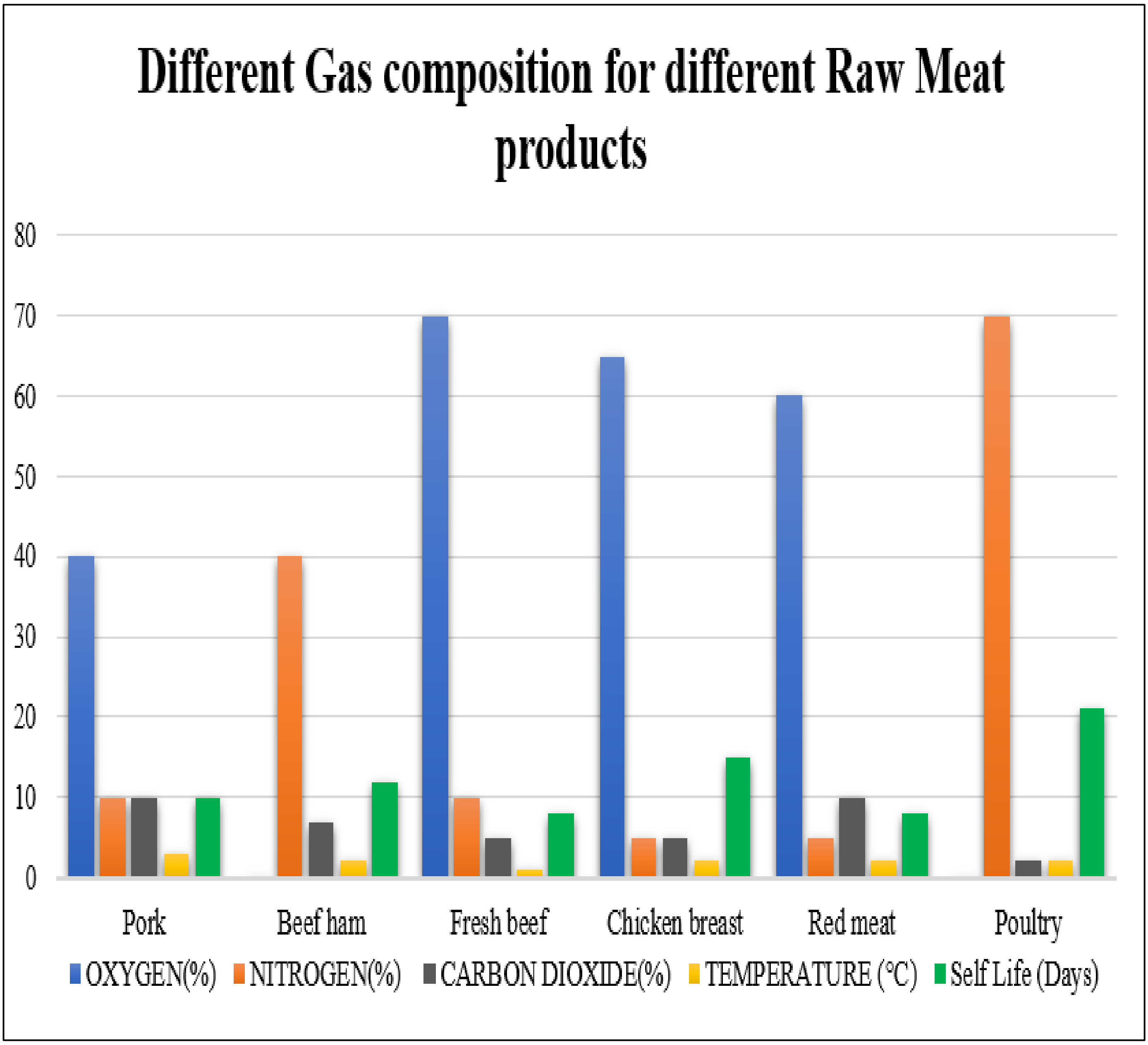

Fig 5: Different Gas Composition for different Raw Meat Products

D. Gas Composition in MAP Technology on Fresh Fish Product [3]

Table 4: Gas Composition in MAP Technology on Fresh Fish Product

Product		**Modified Atmosphere (%)**			**Estimated Shelf Life (Days**
Fish & Sea Food	**Temperature**(°C)	**N2**	**O2**	**CO2**	
Oily fish	2	40-60	00	40-60	10
White fish	2	00	40	60	12
Crustacea	2	00	00	80-100	8
Chub mackerel	2	30	0-20	50-70	15
Salmon slices	2	00	00	100	55
Sardine fillets	2	50	00	50	21
Tuna fish	2	00	60	40	14
Prawn	2	00	00	40	10

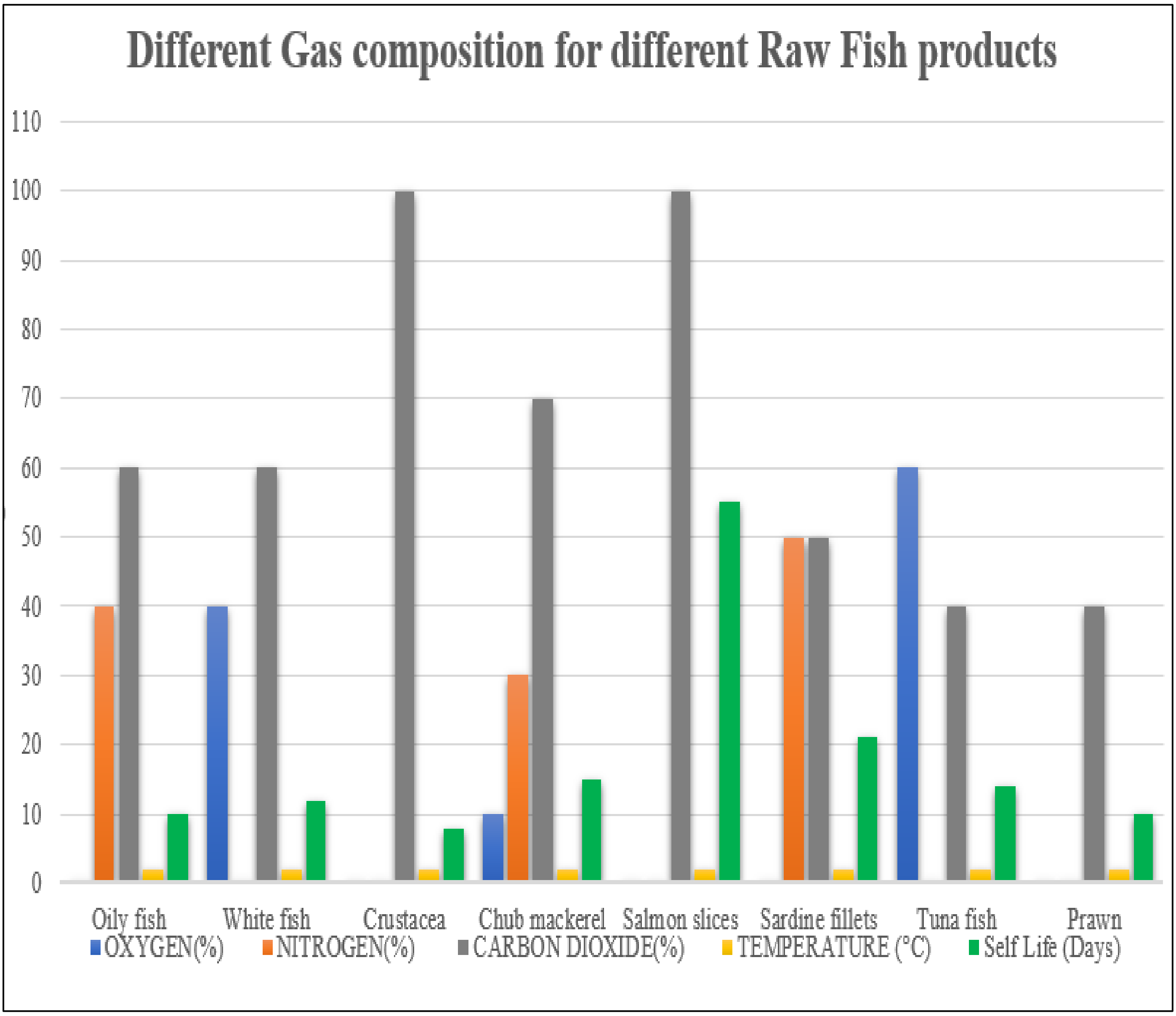

Fig 6: Different Gas Composition for different Raw Fish Products

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E. Gas Composition in MAP Technology on Fresh Bakery Product [4]

Table 5: Gas Composition in MAP Technology on Fresh Bakery Product

Product		**Modified Atmosphere (%)**			**Estimated Shelf Life (Days**
Other Food	**Temperature(°C)**	**N2**	**O2**	**CO2**	
Bakery Product	20-25	20-50	00	50-80	7
Cheese	20-25	30-100	00	0-70	10
Coffee bean	20-25	00	00	40-60	360
Potato chips	20-25	100	00	00	184
Tofu Panner	20-25	70	00	30	21

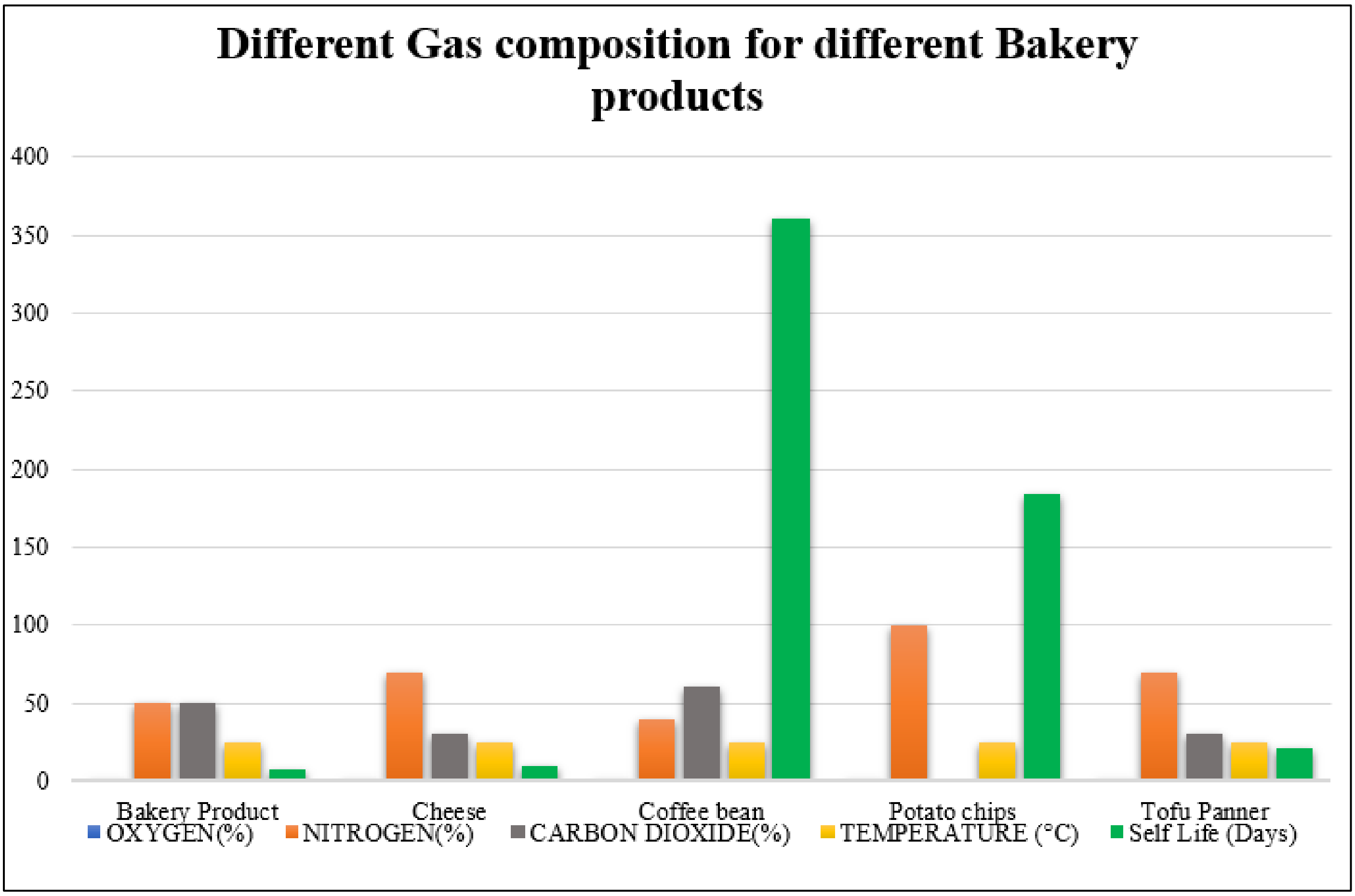

Fig 7: Different Gas Composition for different Bakery Products

VI. EFFECT ON MICROORGANISM GROWTH

Table 6: Effect of CO_2 Atmosphere on Growth of Microorganism [4]

Microorganism	Growth Type	Effect of CO_2 on growth
Aeromonas spp.	Facultative	Inhibited (weakly)
Bacillus cereus	Facultative	Inhibited
Campylobacter jejuni	Microaerophilic	Inhibited, survival
Clostridium botulinum proteolytic (A, B, F)	Anaerobic	Unaffected
C. botulinum nonproteolytic (B, E, F)	Anaerobic	Unaffected
Clostridium peifringens	Anaerobic	Inhibited
Escherichia coli	Facultative	Inhibited (weakly)
Salmonella	Facultative	Inhibited
Vibrio cholerae	Facultative	Inhibited
Yersinia enterocolitica	Facultative	Inhibited

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Table 7: Oxygen Requirements of Some Microorganisms of Relevance in MAP [6]:

Group	Spoilage Organism	Pathogens
Aerobes (require atmospheric O_2 for growth)	Micrococcus sp.	Bacillus cereus
	Molds, e.g., Botrytis cinerea	Yersinia enterocolitica
	Pseudomonas sp.	Vibrio parahaemolyticus Campylobacter jejuni
Microaerophiles (require low levels of 0, for growth)	Lactobacillus sp.	Listeria monocytogenes
	Bacillus spp.	Aen9monas hydrvphila
	Enterobacteriaceae	Escherichia coli
Facultative anaerobes (grow in presence or absence of O_2)	Brochothrix thermosphacta	Salmonella spp.
	Shewcuzella putrefaciens	Staphylococcus spp.
	Yeasts	Vibrio sp.
Anaerobes (inhibited or ldlled by O_2)	Clostridium sporogenes	Clostridium perfringens
	Clostridium tymbutyricum	Clostridium botulinum

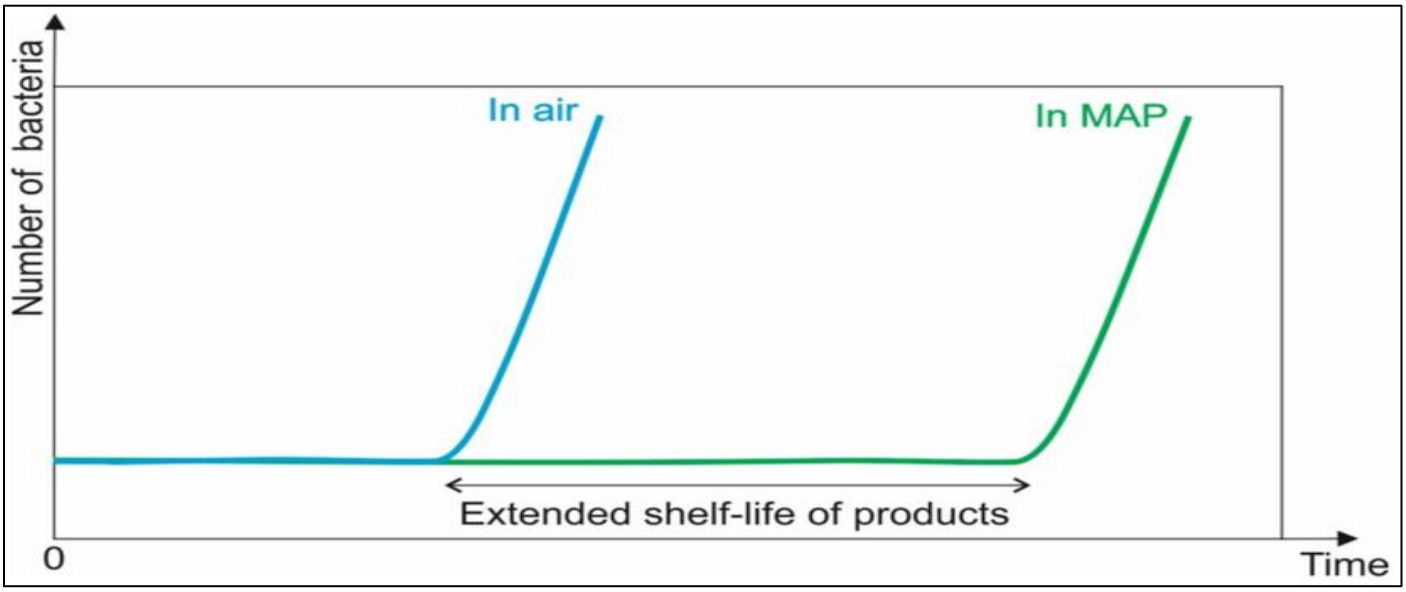

Fig 8: Graphical Compression Between Normal Atmosphere Storage and Modified Atmosphere Storage of Food Products

In this graph we can observe that with respect to time when we kept a food product in a normal atmosphere storage condition, in the food product the growth of microorganism is very rapidly that's why self-life in normal storage is very less, but when the food product is kept in Modified Atmosphere Storage condition microbial growth in food is very slow, as a result the self-life of the food product is extended. This is the main reason to use of the modified atmosphere storage for post-harvest storage of food and processed food product [40].

VII. CONCLUSION

Modified Atmosphere Packaging (MAP) has emerged as a pivotal technology in the preservation and extension of shelf life for various food products. By altering the atmospheric composition within packaging, MAP effectively slows down the metabolic processes of spoilage microorganisms and delays oxidative reactions, thereby maintaining the sensory and nutritional quality of foods. The versatility of MAP in accommodating a wide range of perishable goods—from fresh produce to meat and dairy products—demonstrates its critical role in modern food supply chains.

The advancement of MAP technologies, including the development of intelligent and active packaging systems, continues to enhance its efficacy and adaptability. Innovations such as sensor-integrated packaging and bio-based materials address both the demand for sustainability and the need for real-time monitoring of food quality. Despite the initial costs associated with MAP, the long-term benefits, including reduced food waste and improved food safety, provide significant economic and environmental advantages.

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However, the implementation of MAP requires careful consideration of specific product requirements, as well as an understanding of the interactions between packaging materials and food products. Future research should focus on optimizing gas mixtures for different food categories, developing cost-effective and environmentally friendly packaging solutions, and ensuring regulatory compliance across global markets. In conclusion, MAP stands out as a vital strategy in food preservation, with ongoing research and technological advancements poised to further elevate its impact. The adoption of MAP not only supports the delivery of high-quality food products to consumers but also contributes to a more sustainable and efficient global food system.

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