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A Review on Advanced Preservation Techniques for Post-harvest Quality Maintenance of Fruits and Vegetables

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This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Fruits and vegetables preservation is critical for reducing post-harvest losses, increasing shelf life, and ensuring year-round availability of seasonal goods. It approach is meant to preserve the nutritional value, taste, texture, and color of fresh food while preventing spoiling caused by microbes, enzymes, and environmental influences. There are three types of preservation methods: physical, chemical, and biological. Refrigeration, freezing, and drying are examples of physical preservation processes, as are heat treatments like pasteurization and canning. Refrigeration

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reduces microbial growth and enzymatic activity, whereas freezing stops both, allowing fruits and vegetables to be stored for longer periods. Drying procedures include sun-drying, dehydration, vacuum drying, and freeze-drying, all of which remove moisture and restrict microbial activity. Canning is the method of destroying microorganisms with heat and putting them in an airtight container to prevent contamination. Chemical preservation methods include sulphur dioxide, sodium benzoate, and citric acid. Sugar, salt, acids, and spices are food additives used to preserve fruits and vegetables. In Fermentation, microorganisms such as bacteria and yeast convert sugars into acids or alcohol, producing an environment that prevents spoilage organisms from growing. Finally, conclusion preserving fruits and vegetables is an important part of food security and quality management. A combination of traditional and modern technologies, suited to the individual demands of different types of produce, is critical for reducing waste and providing a consistent supply of nutritious foods year-round.

Keywords: Preservation; physical; chemical; biological; bacterial and food additive.

1. INTRODUCTION

Fruits and vegetables preservation is an important procedure in the global food supply chain that aims to increase the shelf life of these perishable items while reducing post-harvest losses. Fruits and vegetables, which are strong in vitamins, minerals, and antioxidants, are key components of a balanced diet; nevertheless, their high water content and biological makeup make them very prone to spoiling. Without adequate preservation procedures, these items can soon decay, resulting in nutritional loss, food waste, and financial losses for farmers and retailers. The art and science of food preservation have thus become critical to ensuring that fruits and vegetables are available year-round, even when out of season, and that their nutritional and sensory attributes remain intact for extended periods. The country's horticulture production in 2023-24 (Second Advance Estimates) is expected to be approximately 352.23 million tonnes. Fruit production is predicted to exceed 112.63 million tonnes (PIB, Second Advance Estimates 2023–24). The production of vegetables is expected to be around 204.96 million tonnes. India's share in global trade of horticulture produce is 0.6% only. Out of many reasons assigned to the situation, poor post- harvest handling is strong one of them. In India, less than 2% of total production of fruits and vegetables are processed. The figures are 65% in US, 70% in Brazil, 78% in Philippines, 80% in South Africa and 83 % in Malaysia. The extent of value addition is only 7% in India as against 23 % in China and 88% in UK.

According to the most recent large-scale analysis undertaken by NABCONs from 2020 to 2022, India loses approximately ₹1.53 trillion ($18.5 billion) in food annually. Reducing post-harvest losses (PHL) is far more cost effective and beneficial to nature's fundamental resource endowment, which includes soil, water, air, and biodiversity, than producing more and losing more (Gulati *et al*., 2024). The market for agricultural products, including fresh produce and processed foods, has expanded rapidly as consumers believe that environmentally friendly products are superior and healthier. Food safety and product quality must be maintained until they are consumed. In 2023-24, processed fruits and vegetables, including pulses, will be exported for Rs. 20,623.70 crore/USD 2,488.72 million, with processed vegetables, including pulses, worth Rs. 14,339.94 crore/USD 1,730.79 million and processed fruits and juices worth Rs. 6,283.76 crore/USD 757.93 million (APEDA, 2024). Despite the utilization of modern storage facilities, postharvest losses are projected to be between 10 and 35% per year (fruits, 10 to 25%; vegetables, 15 to 35%). A large amount of fresh fruits and vegetables are occasionally detached by typhoons or lightly harmed by pests. Processing technology for these crops are necessary to decrease environmental contamination while increasing farmers' revenue. Harvesters are urged to discard low-quality fruits and vegetables in the field. Another method for reducing deterioration is to eliminate ethylene gas; its accumulation can be reduced and regulated by providing proper ventilation.

The utilization of contemporary storage and packing technologies, as well as the cold chain, are all vital in decreasing postharvest losses. The primary purpose of preserving fruits and vegetables is to postpone the natural spoiling processes, which are caused by microbial growth, enzymatic reactions, and physical changes. Spoilage is produced by microorganisms such as bacteria, molds, and yeasts that feed on the organic content in fruits and vegetables, resulting in fermentation, decay, and unpleasant flavors. Furthermore, enzymatic processes within the produce can cause undesirable color, texture, and flavor changes even after harvest (Jongen, 2002).For example, enzymatic browning in fruits such as apples and bananas is a typical problem that reduces their visual appeal. As a result, preservation procedures are intended to restrict or eliminate these spoiling mechanisms by generating circumstances that inhibit microbial activity and enzymatic destruction (Bose *et al.* 1993). The concepts of preservation are centered on managing critical variables such as moisture, temperature, pH, and oxygen levels. By adjusting these factors, we can slow or stop the degradation process. One of the key concepts of food preservation is to reduce water activity, which refers to the amount of free water accessible in food for microbial development. Microorganisms require moisture to exist, thus removing or lowering water, such as through drying or dehydration, can dramatically increase the shelf life of fruits and vegetables. Temperature management is also important; microbial activity and enzyme action can be slowed or stopped by either reducing the temperature (refrigeration or freezing) or raising it (canning, pasteurization). Furthermore, making the atmosphere more acidic (by fermentation or the use of vinegar) inhibits bacterial development. Oxygen control, achieved through vacuum sealing or modified environment packaging, is another typical way to avoid oxidative deterioration and the growth of aerobic bacteria. To counteract spoiling, mankind have created a variety of preservation methods over the millennia (Singh, 2010).

Traditional methods of harvest preservation and food availability have been employed for millennia, including sun-drying, salting, fermenting, and pickling. Drying, one of the oldest processes, eliminates moisture from fruits and vegetables, inhibiting microbial growth. Salting works by removing moisture and generating a high-salinity environment in which bacteria cannot survive. Fermentation, another old process, uses beneficial bacteria to turn sugars into acids, preserving the produce and improving its flavor. Pickling, which is commonly done with vinegar or brine, reduces the pH of fruits and vegetables, resulting in an acidic environment that discourages rotting germs. Modern technology has offered more efficient and scalable means of preservation, such as refrigeration, freezing, canning, pasteurization, and chemical preservation (Chadha, 2001). Refrigeration reduces the growth of spoilage organisms by keeping product at low temperatures, whereas freezing completely stops microbial and enzymatic activity, allowing fruits and vegetables to be stored for long periods of time without losing quality. Canning is the process of sealing food in airtight containers and heating it to remove harmful germs, which can increase the shelf life of fruits and vegetables by several years. Pasteurization, which is often used for juices and other liquid-based products, entails heating the product to a specified temperature for a defined period of time in order to kill harmful bacteria while preserving flavor and nutrients. Furthermore, current packing techniques like as vacuum sealing and the use of modified atmospheres (in which oxygen is replaced by inert gases such as nitrogen or carbon dioxide) help to preserve fruits and vegetables by reducing oxygen exposure, which delays decomposition and oxidation (Fageria, *et al.* 2016). Chemical preservatives, such as sulfur dioxide and ascorbic acid, are another approach for preserving the color, flavor, and texture of fruits and vegetables while suppressing microbial development. These molecules work as antioxidants and antibacterial agents, keeping the produce fresh and safe to consume. To summarize, the ideas and methods of preserving fruits and vegetables are critical for maintaining food quality, avoiding waste, and ensuring food security. Understanding and utilizing these preservation strategies allows us to keep fruits and vegetables nutritious, safe, and delightful for longer periods, especially in the face of seasonal changes and worldwide distribution obstacles. Whether using conventional or new procedures, effective fruit and vegetable preservation is critical to feeding the world's rising population while minimizing food loss and preserving the integrity of our food system (Peter, 2009).

2. PRINCIPLE OF PRESERVATION

In horticulture, preservation refers to the processes and techniques used to keep fruits and vegetables from spoiling, decaying, or becoming contaminated, hence extending their shelf life while retaining nutritional value, texture, and flavor. Preservation methods try to inhibit the action of bacteria, yeast, molds, and enzymes that cause food spoilage.

It is based on limiting the damage caused by spoiling agents. The general principles involved in preventing the spoiling of horticulture produce are as follows (Meena and Suresh Kumar, 2013, Annonymous 2023–24.).

A. Prevention or Delay of Microbial Decomposition

1. By keeping out the microorganisms
2. By removal of microorganisms
3. By hindering the growth and activity of microorganisms
4. By killing the microorganisms

B. Prevention or Delay of Self-Decomposition of Food:

1. By inhibiting or inactivating enzymatic activity
2. By prevention or delay the non-enzymatic chemical reactions

C. Prevantion of Damage by Mechanical, Insect and Animal causes etc.

A. PREVENTION OR DELAY OF MICROBIAL DE-COMPOSITION

1. By Keeping Out the Microorganism

The safety, quality, and durability of food products are all dependent on the fundamental premise of food preservation, which involves keeping microbes out. The main goal of this strategy is to stop foodborne illnesses and spoiling brought on by dangerous bacteria, molds, and yeasts. Sterilization, which includes the total eradication of all germs using processes like autoclaving, pasteurization, and irradiation, is one of the best ways to do this. Furthermore, enclosing food in airtight containers, such vacuum-sealed bags or jars, forms a barrier that keeps out outside contaminants. Controlling the temperature is also essential; freezing or chilling food inhibits or slows down microbial growth, and heat treatments can destroy dangerous organisms. Fruits and vegetables naturally cover their peels to ensure aseptic conditions. One effective method of asepsis is to package the produce according to the right guidelines. Packaging keeps microbes out of food by serving as a barrier of entrance (James and Kuipers, 2003)

2. By Removal of Microorganisms

In order to improve food safety and prolong shelf life, filtration is a crucial technique in the food preservation concept that focuses on the elimination of germs. In this procedure, food or drink is passed through a filter, which acts as a physical barrier to keep out undesirable microbes including mold, yeast, and bacteria. Making beverages like juices, wines, and bottled water is one of the main uses of filtration in food preservation. In these situations, membranes having hole diameters tiny enough to catch bacteria while permitting liquids and smaller molecules to flow through are frequently used in microfiltration or ultrafiltration procedures. Filtration is an excellent technique for heat-sensitive materials that conventional preservation techniques might not be able to handle since it can accomplish a high level of germ elimination without the use of heat or chemicals (Mustafa and Imran, 2021). Furthermore, filtration can improve the finished product's clarity and general quality in addition to eliminating germs. For example, filtering fruit juices to remove pulp and sediment enhances their appearance and flavor while also guaranteeing safety by getting rid of dangerous microbes. In addition to liquid foods, some solid foods can also be processed using filtration; in these cases, gas or air filtration systems can help keep production facilities sanitary. Filtration is essential to maintaining the safety of food items for consumers by preventing microbial contamination during production and packing. All things considered, filtering is a useful method of food preservation that blends safety and quality, greatly enhancing the integrity of food products sold on the market (Cao *et al.* 2023).

3. By Hindering the Growth of Microorganisms

A basic principle of food preservation is inhibiting the growth of microorganisms, which aims to prolong the shelf life of food items and stop spoiling by establishing unfavorable conditions for microbial development. This strategy is essential for preserving food safety and making sure that goods are safe to eat over time. The best techniques for preventing microbial development:

- **Temperature Control**. Refrigeration greatly extends the freshness of perishable goods like meats, dairy products, and vegetables by slowing down the metabolic processes of microbes. Food stored at temperatures lower than 40°F (4°C) significantly inhibits the growth of harmful microorganisms. Freezing takes this idea a step further; it is one of the greatest solutions for long-term food storage because temperatures below 0°F (-18°C) essentially stop any microbial activity (Basediya *et al.* 2013).

- **pH adjustment.** It is yet another essential method for preventing the growth of microorganisms. Because many bacteria prefer surroundings with a pH of neutral, changing the acidity of food can prevent them from growing. For example, pickling food in vinegar produces an acidic environment that many germs that cause spoiling cannot survive in. In addition to preserving the food, this process adds distinctive flavors. Similar to this, high salt concentrations used to cure meats use osmosis to extract moisture from microbial cells, which efficiently dehydrates and kills hazardous organisms while also improving texture and flavor.
- **Chemical preservatives.** Chemical preservatives like KMS and sodium benzoate are commonly added to processed foods in order to prevent the growth of microorganisms. By interfering with microbes' metabolic processes, these substances prolong the shelf life of goods. Despite their effectiveness, some consumers prefer natural alternatives to chemical preservatives, which are frequently controlled to guarantee consumer safety.
- **Dehydration.** It is yet another powerful method for preventing the growth of microorganisms. This technique lowers water activity, which is essential for microbial survival, by drying up food. This technique is used in preserved goods like as meats, dried fruits, and herbs. There are several ways to accomplish the drying process, each with its own advantages, such as air drying, sun drying, and freeze-drying.

The idea of preventing the growth of microbes includes a wide range of methods used to guarantee the longevity, quality, and safety of food. Food preservation techniques successfully generate conditions that inhibit microbial development by adjusting environmental elements including temperature, pH, moisture, and the presence of preservatives. This enables consumers to enjoy safe and nourishing products for longer periods of time.

4. By Killing the Microorganisms

A key component of food preservation is the idea of killing microorganisms, which aims to get rid of dangerous bacteria, yeasts, and molds to increase food safety and shelf life. This method is vital in preventing foodborne diseases and spoiling. Some of the best techniques for eliminating germs (Muthukumar and Selvakumar, 2017).

- **Heat Treatment**. Pasteurization and sterilization are examples of heat treatment procedures. Pasteurization is the process of heating liquids, like milk or juice, to a certain temperature for a predetermined amount of time in order to destroy harmful bacteria and maintain the quality of the meal. However, sterilization, which is usually accomplished by autoclaving or canning, is a more rigorous procedure that eliminates all bacteria, including spores.
- **Irradiation**. It is yet another efficient method of eliminating microbes. By subjecting food to ionizing radiation, this technique successfully breaks down the DNA of bacteria, parasites, and fungi, preventing them from proliferating and causing spoiling or disease. Irradiation is frequently used to improve the safety and shelf life of foods like dried fruits, spices, and some fresh products (Kalyani, and Manjula 2014).
- **High Pressure Processing (HPP)**. It is a novel method that preserves the nutritional value and sensory appeal of food by using extremely high pressure to kill bacteria without the use of heat. This process is becoming more and more common in the manufacturing of juices and prepared foods (Balasubramaniam *et al.* 2008).

B. PREVENTION OR DELAY OF SELF- DE-COMPOSITION OF FOOD

1. By Inhibiting or Inactivating Enzymatic Activity / Blanching

A heat procedure called blanching is used to stop food, especially fruits and vegetables, from deteriorating and spoiling while being stored by deactivating their enzyme activity. Unwanted changes including browning, flavor loss, and texture changes can be brought on by enzymes such polyphenol oxidase, lipoxygenase, and peroxidase. Blanching is the process of quickly chilling food in ice water after briefly exposing it to boiling water or steam for a few minutes. Produce is treated with steam or boiling water for two to five minutes to achieve this. By denaturing the enzymes' proteins, this abrupt heat exposure makes them inactive and stops the biological processes that lead to spoiling (Srivastava and Kumar, 2017). To prevent the product from becoming overly soft, the cooking process must be stopped quickly. to maintain the original flavor and color. The food's color, flavor, and nutritional value are preserved while the enzymes causing these reactions are destroyed. Blanching is a crucial step in food preservation because it prolongs the shelf life of food goods by stopping enzyme activity. Blanching helps clean the food, lower the microbial burden, and get it ready for additional processing like freezing or canning, all while maintaining freshness. Blanching must be done correctly since too much blanching might destroy nutrients and too little blanching can further activate enzymes (Chen *et al*., 2024)

2. By Prevention or Delay of Chemical Reaction / antioxidant

Because they stop oxidation, a chemical reaction that can cause food quality to deteriorate, antioxidants are essential for food preservation. When food comes into contact with oxygen, it undergoes oxidation, which can cause unwanted changes including rancidity in fats and oils, color loss in fruits and vegetables, and the breakdown of vital minerals like vitamins A and C. Antioxidants prolong the shelf life of food goods by slowing down or blocking these oxidative reactions. They prevent food from spoiling by neutralizing free radicals, which are extremely reactive chemicals that cause oxidation (Kumari, 2022). Vitamin E (tocopherol), vitamin C (ascorbic acid), and carotenoids are examples of natural antioxidants that are frequently utilized in food preservation, especially in oils, nuts, and processed foods that are prone to rancidity. To preserve fats and oils in packaged foods, synthetic antioxidants such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) are also frequently utilized. These substances aid in extending the shelf life of foods by preserving their color, flavor, and nutritional content. Antioxidants not only directly prevent oxidative damage but also cooperate with other preservation methods such as vacuum packing and refrigeration. All things considered, antioxidants are crucial for preserving food quality, cutting down on waste, and guaranteeing that food stays wholesome and safe while being stored (Cömert and Gökmen 2018)

C. PREVENTION OF DAMAGE BY MECHANICAL, ANIMALS AND INSECTS

Preventing damage from mechanical forces, animals, and insects is a critical aspect of food preservation, as physical damage can lead to accelerated spoilage and quality loss. Mechanical damage, such as bruising, cuts, or crushing during harvesting, handling, or transportation, exposes food to oxygen and microbial contamination, triggering processes like enzymatic browning and decay. Proper handling techniques, such as using padded containers, careful stacking, and mechanized sorting, help minimize physical damage to fresh produce. Additionally, packaging plays a key role in protecting food from mechanical harm, with materials like cushioned crates, shock-absorbent films, and moisture barriers preventing physical impacts and maintaining freshness. Food is seriously threatened by animals and insects, especially during the post-harvest and storage stages. In addition to eating food, pests like rats, birds, and insects can contaminate it with their droppings, saliva, or pathogens. Rapid spoiling, health hazards, and financial losses may result from this. Numerous pest management techniques are used to address these problems. These consist of pest-proof packaging, appropriate storage facilities with sealed containers, and environmental controls like low humidity or temperature to prevent pest infestation. Biological controls, insecticides, traps, and pheromone disruptors are examples of integrated pest management (IPM) techniques that are frequently used to prevent pest damage to crops and stored food (https://indiaagronet.com).

3. METHODS OF PRESERVATION IN FRUITS AND VEGETABLES

A. Bacteriostatic Methods

The term "bacteriostatic method" describes a procedure or material that prevents bacteria from growing and reproducing without necessarily killing them (FAO, 1998). This technique successfully stops the spread of infection or spoiling by keeping the bacterial cells alive but stopping them from proliferating. These are

1. Drying of Foods

One of the oldest and most popular ways of food preservation is drying, which works on the basis of removing moisture to prevent the growth of bacteria, yeast, and molds, as well as the enzymatic activity that causes food to deteriorate. Drying drastically reduces the water activity by lowering the water content, usually to less than 10%, which makes the environment unfavourable for chemical reactions and microbiological growth. When done correctly, this process preserves many of the food's original nutrients, flavors, and characteristics, making it a valuable tool for extending the shelf life of a variety of items, including fruits, vegetables, meats, cereals, and herbs. Different drying methods are available, each suited to a particular food type and intended result. One of the earliest and most basic techniques is sun drying, which depends on ambient airflow and sunlight. In areas with hot, dry weather, it is still frequently used, especially for drying fruits like figs, raisins, and apricots. Its drawbacks include its susceptibility to contamination, insects, and weather-related drying irregularities. A more regulated technique is air drying, which involves moving warm air around the food to eliminate moisture (Singh, 2011). In commercial food processing, this method is used to make dry products including jerky, dried herbs, and pasta. Compared to conventional air or sun drying, dehydrators or mechanical dryers provide even more control by drying food more quickly and reliably using electric heat and fans. A more sophisticated method called freeze drying entails freezing the food and then using a vacuum to sublimate (transform from ice to vapor without going through the liquid phase) the water. Because it preserves a large portion of the food's original structure, flavor, and nutritional value, this approach works very well for preserving delicate goods like fruits, coffee, and even ready-to-eat meals. Food is atomized into a fine mist and then quickly dried in hot air to produce powders. Spray drying is frequently used for liquids like milk or juice (Sehrawat *et al.* 2018).

2. Use of Chemical Preservative

One essential tactic for extending the shelf life and guaranteeing the safety of food goods is the use of chemical preservatives, which stop microbiological development and spoiling. These preservatives function by preventing the growth of bacteria, molds, and yeasts—organisms that cause food to deteriorate and can be harmful to one's health. There are two primary categories into which chemical preservatives category:

- For ages, people have used natural preservatives including salt, sugar, vinegar, and citric acid. Salt, for example, works by removing moisture from food and microbes through osmosis, so making the environment unsuitable for bacterial growth. Similar to how sugar reduces water activity to preserve fruits in jams and jellies, vinegar and citric acid drop food pH, making it too acidic for the majority of microorganisms to survive (Ahmad *et al*. 2021)
- Commonly found in processed foods, synthetic preservatives include substances like potassium sorbate, sodium benzoate, nitrates, and sulphites. Because it inhibits the growth of yeasts, sodium benzoate works well in acidic environments like salad dressings and soft beverages. 750 parts per million Fruit juices, squash, and cordinal are the main products that contain sodium benzoate. While sulphites are used in dried fruits and wines to stop browning and fermentation, potassium sorbate is frequently used in dairy products, baked goods, and wines to stop the growth of mold and yeast (Vasantha and Yu, 2012). KMS is used to control germs and mold in fruit with pigment that is not a water

solvent. Synthetic preservatives are effective, but their use has sparked health concerns, particularly among consumers looking for "clean-label" products with fewer artificial components. Sensitivities to specific preservatives, such sulphites, can cause allergic reactions in certain people (Silva and Lidon, 2016).

3. Use of Natural Food Additive

Natural Natural food additives are essential for food preservation because they improve the nutritional value, safety, and quality of food products while providing efficient substitutes for artificial ingredients. These additives, which come from plant, animal, or mineral sources, are becoming more and more popular among customers looking for healthier options and clearer labels. Natural preservatives including salt, sugar, vinegar, and essential oils are among the main applications of natural food additives in preservation (Peter, 2007). By removing moisture from food, salt and sugar create an environment that prevents the growth of mold, yeast, and bacteria. This technique is frequently used to preserve fruits in jams and jellies and cure meats. In addition to adding flavor, vinegar, also known as acetic acid, lowers the pH of food, which makes it less pathogen-friendly. Jelly, jam, squash, and nectar are prepared using citric acid, which raises the acidity. Condiments and spices improve the taste, color, and flavor. They have antifungal and antibacterial properties (Mansuri, ICAR-CAZRI). Antioxidants such as vitamin C (ascorbic acid) and vitamin E (tocopherols), which are found naturally in a variety of fruits and vegetables, can aid in preventing oxidative damage to fats and oils, preserving their nutritional value and freshness. By preventing separation in foods like mayonnaise and salad dressings, these additives enhance the texture and consistency of food products, which can be essential for maintaining product integrity over time (Corbo *et al.* 2009).

4. Use of Low Temperature

One essential method used to increase the shelf life of different food products while preserving their safety and quality is low-temperature food preservation (Liberty, 2013). The growth of bacteria, yeasts, and mold is efficiently inhibited by slowing down the metabolic activities of microorganisms, enzymes, and chemical reactions that lead to spoiling (cellar, refrigeration, and freezing). (Gao *et al*. 2023).

- **Cellar Storage**
  Fruits, vegetables, and wines are among the foods that can be effectively preserved by cellar preservation. By preventing bacteria and fungi from growing, a cellar's chilly, dark, and humid atmosphere slows down spoiling. The ideal temperature range for preserving flavor and freshness is 10°C to 15°C (50°F to 59°F).
- **Refrigeration Storage**
  Perishable goods including fruits, vegetables, dairy products, and meats are best kept in a refrigerator, which is normally kept at temperatures between 0°C and 4°C (32°F and 39°F). This technique maintains the food's nutritional content and sensory qualities while also postponing spoiling (Adam, 1946).
- **Freezing Storage**
  By reducing temperatures to -18°C (0°F) or lower, freezing storage is a common technique for food preservation that successfully stops enzyme reactions and microbiological activity. This method preserves food's flavor, texture, and nutritional content, thus it may be used with a wide range of products, such as prepared meals, meats, and vegetables. In order to reduce the production of ice crystals and preserve quality when thawed, rapid freezing is advised (Barbosa-Cánovas et al 2005).

B. Bactericidal Methods

Any approach or procedure that actively kills germs rather than just preventing their growth (sometimes referred to as bacteriostatic) is referred to as a bactericidal method. Using substances or therapies that damage bacterial cell walls, alter their metabolism, or otherwise impair their structure or function to the point of cell death is a common practice in bactericidal procedures. Among the most popular antibacterial methods are heat treatments like pasteurization and canning (Holdsworth, 1983).

- **Pasteurization**
  In order to lower the microbial load and primarily target pathogenic germs that can

cause foodborne illness, food and beverages are heated to a specific temperature for a predetermined amount of time. This procedure is known as pasteurization. involves raising the temperature of foods like milk, juice, and eggs to a certain point in order to eliminate dangerous bacteria and lower the microbial load. This improves shelf stability without significantly altering the taste or nutritional value of the product. Low Temperature Long Time (LTLT): This conventional technique involves heating goods for 30 minutes to about 145°F (63°C). The faster method known as High Temperature Short Time (HTST) involves heating items like milk to 161°F (72°C) for 15 seconds. Products are heated to 275–302°F (135–150°C) for 2–5 seconds during UHT pasteurization (Choudhary and Bandla, 2012).

- **Canning**
  Food is preserved by canning, which involves putting it in airtight jars or cans and then heating it to a certain temperature to kill any bacteria or enzymes that would cause it to spoil (Rajput et al. 2022). In addition to removing air from the container, this heating procedure creates a vacuum seal that keeps new bacteria out. Foods in cans can maintain their flavor, texture, and nutritional content for extended periods of time provided they are prepared and packed correctly. High Low-acid foods, such meats, vegetables, and soups, must be processed at 240°F (116°C), which is the boiling point of water. High-acid foods, like fruits, tomatoes, pickles, and jams, can be processed at 212°F (100°C). Foods can be properly stored for months or even years thanks to canning, which creates a sterile environment by removing germs and their spores, frequently at higher temperatures and under pressure (Pokhrel, 2020).

- **High Pressure Processing (HPP)**
  Using extremely high pressure, usually between 300 and 600 MPa, High-Pressure Processing (HPP) is a non-thermal food preservation technique that inactivates dangerous microbes and enzymes without the use of heat. HPP greatly increases shelf life and improves safety in a variety of food categories, such as cold-pressed juices, ready-to-eat meats, guacamole, and sauces. Compared to conventional thermal processes, HPP's non-thermal nature protects more vitamins and antioxidants, satisfying consumer desire for minimally processed, clean-label products (Avure, 2007).

- **Ultraviolet (UV)**
  An efficient technique for preserving food is ultraviolet (UV) light, which uses UV rays to render bacteria, viruses, and molds inactive on food surfaces and in liquids. The main way that this non-thermal procedure works is by breaking down the bacteria' DNA, which stops them from multiplying and leading to spoiling or foodborne illness (Keyser *et al.* 2008). Since UV therapy preserves food's nutritional value and sensory qualities without the need of heat or chemical preservatives, it is frequently employed for a variety of purposes, such as the purification of water, juice, and dairy products (Chiozzi *et al.* 2022).

- **Fermentation**
  Fermentation is an ancient and successful fruit and vegetable preservation process that uses helpful microbes, typically bacteria and yeasts, to increase shelf life while improving nutritional and sensory properties. microbes convert the natural sugars in produce into organic acids, alcohol, and carbon dioxide, resulting in an acidic environment that limits the growth of spoilage-causing and pathogenic microbes. This not only preserves fruits and vegetables, but also enhances them with vitamins, enzymes, and probiotics that promote intestinal health. Common Pickles, sauerkraut, kimchi, and fruit-based kombucha are examples of fermented items that have distinct Flavors due to the diversity of microbial activity. The process usually starts with the processing of produce, such as slicing or grating, followed by immersion in a salt brine, which stimulates lactic acid bacteria to dominate and start fermentation. Salt is essential for retaining crisp texture, drawing out water, and suppressing unwanted microbes. Fermented fruits and vegetables not only have a longer shelf life, but they also have distinct, complex Flavors that appeal to consumers who seek artisanal, natural goods (Anand *et al*. 2019).

C. Minimal Processing

Minimal processing in fruit and vegetable crops refers to practices that make fresh produce more handy and ready-to-eat while retaining its natural form and increasing shelf life. This procedure involves washing, peeling, slicing, cutting, and packaging fruits and vegetables while preserving their natural qualities (Luh and Woodroof, 1988). Unlike traditional preservation methods, minimal processing does not use thermal treatments or chemical preservatives to affect flavor, texture, or nutritional content. The goal is to preserve as much freshness as possible while reducing spoiling and microbiological development (Sumonsiri, 2014). Sanitizing to reduce contamination and keeping a regulated environment during packaging to keep fruit fresh are common aspects in the process. Modified Modified atmosphere packing (MAP), which lowers oxygen levels while increasing carbon dioxide levels, is often used to reduce respiration rates and avoid oxidation. This strategy is popular because it addresses consumer desire for fresh, convenient, and healthful food options that do not contain artificial preservatives. However, because minimum processing may not completely eliminate spoilage organisms, the products have a short shelf life and require stringent temperature control throughout distribution and storage. Advances in processing technologies, such as edible coatings and high-pressure processing, are being investigated to improve the quality and endurance of little treated vegetables (Amin, 2017).

4. DISCUSSION AND CONCLUSION

Fruits and vegetables must be preserved to increase their shelf life, preserve their nutritional value, and reduce food waste. This procedure uses a variety of concepts and techniques, with the main goal being to prevent oxidative alterations, microbial development, and enzymatic activity that cause spoiling. Preventing microbial decomposition, food self-decomposition, and mechanical, animal, and insect pests are the primary tenets of fruit and vegetable preservation. Maintaining Pickling, drying, freezing, and canning are examples of traditional methods, each with pros and cons. While freezing maintains freshness by stopping enzyme activity and microbial growth, canning entails enclosing fruits and vegetables in airtight vessels and using heat to kill unwanted germs. Fruits like apricots and vegetables like tomatoes benefit greatly from drying since it lowers moisture content and prevents spoiling. Modern techniques like high-pressure processing (HPP) provide substitutes that preserve the nutritional content and flavor of vegetables without the need of chemical preservatives. The type of fruit or vegetable, the intended shelf life, and market demands all influence the preservation method selection. In conclusion, optimizing the quality and usefulness of fruits and vegetables requires an awareness of preservation concepts and techniques. The creation and use of efficient preservation methods will be essential to maintaining food safety, improving convenience, and advancing sustainability in the food supply chain as consumer preferences shift more and more toward natural and minimally processed foods.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The authors hereby state that no generative AI tools, such as Large Language Models (COPILOT, ChatGPT, etc.) or text-to-image generators, were utilized during the creation and editing of this work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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