Application of Novel Technologies in Shelf- Life enhancement of Fruits and Vegetables

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ABSTRACT

Fruit and vegetables require advanced post-harvest technology to improve its shelf life and to preserve its storage stability. This paper provides an overview of new trends and technologies for extending the shelf life of fruits and vegetables, including edible film and probiotics, Cold plasma, UV-C, Ultrasound, and HHP, as well as their advantages and drawbacks. Each method has advantages and disadvantages, and research is still being conducted to determine which ways are the most practical for each application. The ability of microorganisms to tolerate destruction, the nature of the decontaminated substrate, and the treatment's safety all play a role in determining the best procedure.

KEYWORKS : Fruits and vegetables,edible film, probiotics, Cold plasma, UV-C, Ultrasound

1. INTRODUCTION

Fruits and vegetables are well known for their high nutritional characteristics, which include critical vitamins, minerals, and dietary fibers that are considered important for a balanced diet (Slavin&Lloyed, 2012). The recommended diet package decreases the risk of inadequacies and aids in the maintenance of a healthy lifestyle.

The main thing that affects the shelf life of the fruit and vegetables is the type of fruit or vegetable itselfand time spent in the supply chain (storage, transport) from where it was picked.These fruits and vegetables are transported from fields in various locations to distant markets via a supply chain; without suitable handling and storage techniques, the product's quality may degrade.

Harvested products are metabolically active and undergo maturation and aging processes that must be regulated to maintain post-harvest quality. Poor management of these processes can result in significant loss of nutrition and quality, food poisoning and economic losses for everyone involved in the farm-to-fork supply chain. Fresh fruits and vegetables are perishable staples that require coordinated action by producers, warehouse managers, processors, and retailers to maintain quality and reduce food loss and waste.They are also an excellent source of important vitamins and minerals such as vitamin A, vitamin C and potassium that are necessary for human health (Mahajan et al., 2016). Several research are being undertaken to better understand the effects and outcomes of postharvest quality in connection to time and storage temperature, among other parameters. The number of agricultural products traded worldwide has increased as food globalization has progressed. At the same time, the transport distance and duration have been increased. (Singh et al.,2014).

1.1 Causes of post-harvest losses of fruits and vegetables

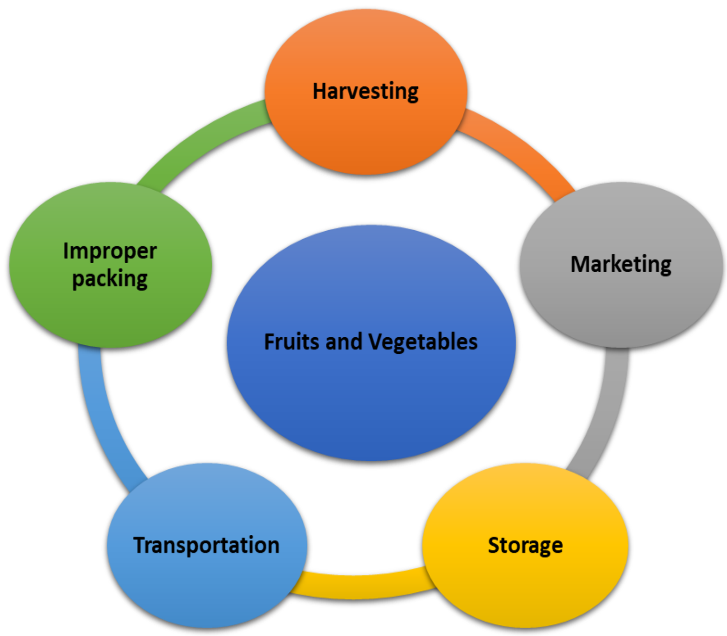

Fig 1: Causes of post-harvest losses of fruits and Vegetables

1.1.1 Harvesting

Ripening during harvest time is the most important element determining product quality and shelf life for fruits and vegetables. However, for economic reasons, some farmers can harvest immature crops. Unripe fruits are more vulnerable to mechanical injury and deterioration, and they may develop bad attributes such as high acidity and low sugar when they ripen. Overripe fruits, on the other hand, have a short shelf life. Fruits are more prone to physiological abnormalities in both circumstances (overripening and under ripening). Harvesting during the hot period of the day which rises the field heat of the produce may cause wilting and shriveling. Harvesting during or after rains an create a favorable condition for the growth of microorganisms.

Early harvesting diminishes crops' nutritional and economic worth. In certain circumstances, entire products are discarded because they are unfit for ingestion (Azabaaolu, 2018). Harvesting procedures can sometimes result in losses (Kasso& Bekele, 2016). When easily perishable goods, such as fruits and vegetables, are subjected to more than one treatment, the losses rise. At the same time, farmers may lack storage containers during the harvesting and post-harvesting processes. This causes mechanical damage during fruit, vegetable, root, and tuber plant harvesting, resulting in some losses.

1.1.2 Storage

After applying some treatments to post-harvest items, such as cleaning, sorting, and packaging, the products may need to be stored for a few hours to a few months. Product storage improves time management and allows for more leisurely marketing and consumption. Of course, this is true when the storage procedure is carried out under appropriate conditions; otherwise, major losses in items such as freeze damage and color changes may occur. Relative humidity and temperature of the storage rooms plays an important role in shelf life of the fresh produce. Sometimes when the products which contain same ideal temperature stored together may reduce the shelf life and can cause bitterness, softening and discoloration because some crops may produce higher amounts of ethylene.

The quality and consumability of the products are dependent on the stage of the entire food supply chain even if it is stored in ideal conditions. Storage begins at the manufacturing stage and is evenly distributed throughout the supply chain in developed countries. Combining refrigerated storage with post-harvest techniques such as controlled environments can significantly extend the shelf life of perishable foods. Lack of adequate storage facilities is the leading cause of post-harvest losses in developing countries.

1.1.3 Transportation

Transportation adds time between production and consumption, it can be one of the leading sources of losses, particularly for fresh items. Delivery of perishables by refrigerated truck is a common practice in developed countries. In such cases, losses occur when the vehicle's cooling system fails, an accident occurs, or delays occur in the loading and unloading areas. Perishables are not properly stored in poorer countries due to lack of suitable means of transport, inadequate roads, and inefficient logistics management.

Moreover, loading and unloading operations in these countries are usually carried out by untrained and uneducated people who handle the goods with care. Mechanical damage occurs in agricultural products because of this (Azabağaoğlu, 2018). Improper transportation of products can cause physical and mechanical injury and uncontrolled conditions like temperature and humidity.

1.1.4 Loss in Market and improper packing

Losses can be greatly reduced by timely and correct harvesting, the use of refrigerated cars for interstate transportation, cold storage, and the use of packaging materials that limit moisture loss. Farmers sell their produce in either fresh or wholesale markets. Fresh produce is sold unpackaged or wrapped in bundles at the retail level. If the fresh produce is not sold immediately, this form of marketing significantly shortens the shelf life (Kiaya, 2014).

Packaging is essential to reduce loss and extend shelf life of fresh fruits and vegetables.

Therefore, one of the main reasons for the loss of fruits and vegetables in the post-harvest stage is improper packaging and use of improper packaging materials. Poor quality packaging materials cannot sufficiently preserve fresh products from harm and can even hasten rotting. Unfortunately, due to their low cost, low-quality packaging materials are frequently used in many regions of the world. Poor quality packaging containers are especially widespread in developing and underdeveloped countries. Even certain delicate fruits and vegetables are packaged in poly-sacks, which cause significant damage to the products.

1.1.5 Microbial Action

Mainly the microbial spoilage of fruits and vegetables caused by fungi, bacteria, yeast and molds. Because of the high moisture content of these products provides favorable conditions for the excellent growth of microorganisms. Many times, serious post-harvest diseases occur quickly and may cause a large-scale collapse of the commodity, sometimes spoiling the entire package. In general fruits are too acidic for the growth of more common foodborne pathogens like Salmonella and Shigella. The presence of pathogens in susceptible host fruits and vegetables, combined with appropriate environmental conditions such as high temperature, provide the three necessary components for disease manifestation: host, environment, and pathogen (Sommer et al.,1992).

1.2 Post Harvesting Scenario

1.2.1 Global

The agricultural sector's largest issue today is feeding a population of more than 9.1 billion people by 2050. (Parfitt et al., 2010). To meet the needs of this rapidly growing population, we need to increase grain production from 2.1 billion to 3 billion tonnes per year and meat production to 470 million tonnes per year. It is estimated that net cereal imports in developing nations will range between 135 million and 300 million tonnes by 2050.

Earlier studies intended to enhance agricultural productivity (by 50-70 percent) to bridge the gap between food demand and supply. In contrast, less emphasis is placed on reducing food waste and post-harvest loss (Hodges et al., 2011). Around 33% of the world's food production is wasted or lost, amounting to approximately 1.3 billion tonnes per year and costing the global economy approximately 750 billion US dollars (Prusky, 2011).

1.2.2 Indian

The agricultural produce in India is worth INR 50, 000 crores; of this, a massive 40% of the total production is wasted every year. In the context of overall wastage of agricultural produce, milk and poultry, India stands at an unenviable seventh position, whereas Russia tops the list. Among food items, fruits and vegetables have short shelf-lives and form 70% of the wasted food, amounting to 40% of the financial loss. India is finding it somewhat difficult to feed its vast population, and food crisis may worsen considerably in the coming decades

Consumers around the world demand high quality food products that are free of chemical preservatives and have a long shelf life. As a result, more effort is being put into developing new natural preservatives and antimicrobials. A number of storage techniques have been developed to extend marketing distances and extend post-harvest storage times for raw materials (Misir et al., 2014).

2. NOVEL PROCESSING TECHNOLOGY

Storage systems available around the world require a low temperature to preserve commodities (Sagar& Kumar, 2010); nevertheless, their higher cost and lack of availability in many locations are significant restrictions. As a result, various strategies offer viable alternatives for reducing losses and preserving fruits and vegetables while maintaining quality. The current review focuses on various procedures and the impact of drying on the preservation and quality of selected fruits and vegetables(Misiret al2014).

2.1 UV-C Rays on fruits and vegetables

The primary goal of developing and implementing postharvest preservation technologies is to maintain the quality of fruits and vegetables while extending their shelf life. the relationship between UV-induced antifungal characteristics in fruits and changes in cell wall ultrastructure, and summarize UV-induced effects on ethylene production, respiration rate, firmness, chlorophyll metabolism, enzymatic antioxidant system, and non-enzymatic antioxidant system Importantly, UV irradiation can promote the enrichment of postharvest phenolic chemicals and boost the nutritional content of fruits and vegetables as a physical technique. This method is considered an alternative to chemical fungicides for post-harvest disease control.

Principle

UV is usually divided into three wavelengths: long wave UV-A (320 nm-400 nm), medium wave UV-B (280-320 nm) and short-wave UV-C (200-280 nm). The sun's rays contain all ultraviolet rays, but only UV-A and UV-B can reach the earth's surface, while UV-C is completely absorbed by the ozone layer and does not reach the earth's surface (Urban et al., 2016).

UV-C mostly manifests in chloroplasts and mitochondria and has a direct cytotoxic effect on plastoquinone. UV-C radiation has been proven in studies to cause programmed cell death (PCD) in Arabidopsis thaliana.

Application

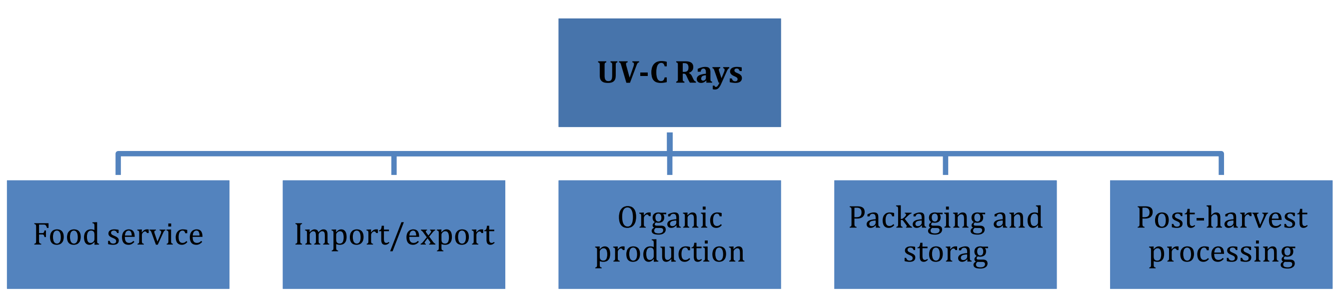

Fig 2: Application of UV-C Rays on fruits and Vegetables

UV-C has been linked to the post-harvest antifungal effects of fruits and vegetables as a residue-free physical sterilization approach (Usall et al., 2016). UV-C has always had a better effect on postharvest fungal diseases of fruits and vegetables. UV-C treatment has been shown to greatly decrease Colletotrichum conidial germination and sporulation on mango.

Low-dose (2.0–4.4 kJ m2) UV-C treatment as an appropriate non-biological stress for fruit and vegetables to induce resistance and hence prevent fungus. The use of non-ionizing, germicidal UV-C light could be effective for the decontamination of fruits and vegetables as a whole or a fresh cut product. UV-C affects several physiological processes in plant tissues and damages microbial DNA.

TABLE 1: Results of Postharvest UV-C treatment of fruit and Vegetables.

S No	Horticultural produce	UV-C dose	Hormetic effect	Reference
1	Blueberry fruit	0-4 kJ/m2	Weight loss and firmness Decay incidence from ripe rot Antioxidants	Perkins-Veazie et al., 2008
2	Grapes	0.36 kJ m^{-2}	Induction of catechin and trans resveratrol	Romanazzi et al. (2006)
3	Strawberry	4.1 kJ.m^{-2}	Increase firmness	Charles et al. (2009)
4	Tomato	3.7 kJ.m^{-2}	Revealed a softening delay	Pombo et al. (2009)
5	Grapefruit	0.5-3.0 kJ/m2	Quality and disease resistance	D'hallewin et al., 2000
6	Onion 30W		Reduced rate of tissue fluid flow and decay	Kasım and Kasım (2012)
7	Sweet potato	3.6 kJ m^{-2}	Enhanced PAL activity	Stevens et al. (1999)
8	Mango	2.46 and 4.93 J/m2	Better overall appearance	GonzalesAguilar et al., 2007

Mode of action

Several researchers gradually found further favorable effects of the treatment due to hormetic effects and phytoalexin synthesis, which are detailed below.

Hormesis

Hormesis refers to stimulation by low dosages of any stimulus (physical or pharmacological). Hormesis is a boost to the "natural defensive mechanism." It is exclusively induced by modest UV exposures ranging from 100 to 280 nm. The hormetic dose differs depending on the dietary matrix, dose rate, and total exposure period.

This effect reduces postharvest deterioration during Horti-produce storage. The two main advantages of UV-induced hormesis are the creation of antifungal chemicals, the suppression of decay, the reduced rate of senescence, the delayed ripening, and the reduction of ripening rate.

These anti-fungal compounds which can be synthesize inside the plant organs include: phytoalexins, pathogenesis related proteins (chitinases, glucanase), flavonoids, phenolic acids, lignin, suberin, as well as the antioxidant enzymes together with catalase, peroxidase, ascorbate peroxidase and polyphenyl ammonia lyase. These components and enzymes restrict the fungal increase at the fruit and decrease disease occurrence severity (Shama and Alderson, 2005; Charles et al., 2008a).

Phytoalexins produced during UV exposure

Phytoalexins are antimicrobial low-molecular weight compounds (secondary metabolites), A low UV-C dose can also stimulate the development of different phytoalexins in a variety of postharvest commodities. Several studies have found a considerable link between phytoalexin accumulation and disease resistance. The ability of a crop to collect phytoalexin in response to UV exposure varies depending on the dose, variety, storage circumstances (temperature and relative humidity), and physiological ages.

Limitations

UV on fresh produce has some advantages, as previously noted, it also has a few drawbacks, which are listed below.

- Low penetration power: Because UV radiation has a low penetration power, it can only be used to successfully pasteurize/sterilize solid surfaces and thin layers of liquids.

- Surface characteristics: The effectiveness of UV rays is dependent on the surface features or "topography" of foods, such as ridges or crevices. Food surface irregularities may protect organisms from incident UV radiation, decreasing the process's efficacy.

- Shielding by solids such as paper, glass, or films: Labeling materials or stickers on whole fruits and vegetables such as apples, mangoes, and so on might hide germs behind them, preventing them from being exposed to incident UV light and limiting efficiency.

- The effect of hormesis on solid foods has not been thoroughly studied:hormesis may result in different substrates at different dosages, leading to the formation of various self-defense systems. When only surfaces (peels, shells, cuticle, bloom, etc.) are changed, the variety in solid foods is significantly greater. More research on hormesis effects in solid foods is needed before a valid conclusion can be formed.

- The effect of UV on yeast population has yet to be determined: The effect of UV on fungi has been researched, but molds have received more attention than yeast (Sethiet al.,2018).

2.2 Cold plasma technology on post-harvest fruits and vegetables

Cold plasma technology is gaining popularity due to its excellent efficacy in removing germs from fruits and fruit-based goods. Plasma processing, as a nonthermal technique, preserves the quality of fruits while minimizing the thermal effects on nutritional qualities. Cold plasma is also used to inactivate enzymes and degrade pesticides, both of which are directly related to quality loss and are currently major concerns in the fresh produce business. The current review focuses on the impact of cold plasma technology on minimizing microbiological threats and improving fruit quality features.

Principle

Plasma is created by adding mechanical, thermal, chemical, and radiation energy to a gas mixture, causing ionization of the gas (low or atmospheric) and the formation of active species such as electrons, free radicals, ions, and so on (Pignata et al. 2014). Plasma can exist in ground or excited states and has net neutral charges (Weltmann et al. 2010).

Cold plasma is a powerful thermodynamic non-equilibrium state with high reactivity, making it suitable for a wide range of applications in industries such as agriculture, food, packaging, medical, and so on.

Application

The fruit business is constantly on the lookout for effective methods to manage microbial infection and storability while minimizing the impact on quality attributes such as color, flavor, and phytochemical retention. Various plasma sources have been used to inactivate various microbiological infections. For instance,(Mir, Shabir et al. 2019) reported the inactivation of Salmonella and E. coli O157:H7 in cantaloupe and apple, respectively, using atmospheric glow discharge plasma. At room temperature, atmospheric glow discharge plasma has been shown to be efficient against active microbial species, lowering log numbers of bacteria, bacterial endospores, yeasts, and other microbes.

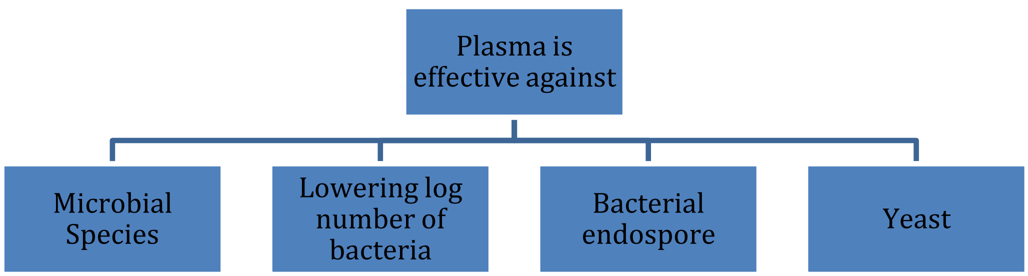

Fig 3: Application of atmospheric glow discharge plasma at room temperature

Mode of action

Inactivation Mechanism

Various researchers' microbial inactivation tests revealed that cold plasma might dramatically damage the cell envelopes, proteins, and nucleic acids of spoilage microorganisms. Plasma-generated particles caused physical damage to microbial cell membranes (Lackmann et al., 2013). Cold plasma generated by atmospheric pressure is known to have bactericidal properties due to fast enzyme/protein inactivation and nucleobase alteration. It was also shown that the vacuum, UV photons, and charged species produced by cold plasma have synergistic effects on each other at the molecular level.

The cell death of Candida albicans caused by dielectric barrier discharge was described, and the main cause was the release of cytoplasm caused by the disintegration of exterior structure. Bacterial membranes/envelopes are made up of lipids and/or other exo-polysaccharides that can be oxidized by free radicals created by cold plasma. As a result, the sterilization effects of cold plasma should not be only based on the number of culturablecells but should also consider viability counts.

Degradation of pesticides

Pesticides are now widely employed by farmers and orchardists to protect plants against fungal and bacterial illnesses and to boost productivity. These pesticides remain intact in the fruit and have negative health consequences on consumers.

The use of oxygen plasma treatment has a considerable impact on organophosphorus pesticide breakdown efficiency. The degradation efficiency is affected by operating parameters such as exposure period, discharge power, distance from the center of the induction coil, and organophosphorus pesticide concentrations. Organophosphorus pesticides were found to break down into less hazardous chemicals than the parent pesticide molecule.

Enzyme inactivation

Enzymes are responsible for a variety of catabolic and anabolic activities in biological systems. As previously noted, in the case of fruits and fresh-cut items, several enzymes such as PPO and POD have a detrimental impact on phenolic metabolism, resulting in a loss of flavor, color, and nutritional content.

According to Surowsky et al. (2013) the effect of cold plasma on the activity of quality-determining enzymes such as PPO and POD. On plasma treatment time, PPO activity was lowered by 90%. POD was shown to be more stable than P and lowered by 85 percent after 240 seconds of treatment.

Cold plasma has been shown to successfully reduce the incidence of browning in fresh items, resulting in quality preservation for a longer period (Sharma et al.,2018).

Advantages

As an emerging technology, cold plasma is quite effective, as demonstrated by the following:

- Cold plasma technology provides better microbial inactivation at low temperatures, it improves supply chain potential efficiency by increasing shelf life.
- In situ synthesis of active species based on the requirement and range of accessible gasses, cold plasma technology is compatible with mostof packaging and modified atmospheres.
- Cold plasma includes very diffusive chemical species that can rapidly sterilize entire food surfaces.
- This method appears to have no impact on the product matrix and looks to be safe with mostof food goods.
- Cold plasma technology is an environmentally beneficial solution because it is free of water/solvent and reduces the use of typical preservatives.
- In general, cold plasma leaves no leftovers if enough time is allowed for recombination events to occur. This, however, may not be uniformly true and necessitates extensive validation investigations.
- It is also worth noting that the technology is applicable to both solid and liquid foods. The numerous plasma source configurations allow for the generation of plasmas in various gas atmospheres (to treat a variety of produce) as well as underwater (or liquid) discharges (Sharma et al.,2018).

Limitations

The following are some of the limitations of cold plasma technology:

- The cost of cold plasma is mostly determined by the cost of the gas mixture used to generate the plasma, and it may be costly if operated with noble gasses.
- Very high voltages are employed for cold plasma creation, additional safety precautions are required. Appropriate gas destruction and exhaustion procedures are also necessary.
- Currently, one of the key challenges in cold plasma treatment of meals is accurately managing the chemistry of the gas plasma processes, which is complicated by the changing degrees of humidity brought by foods.
- Cold plasma produced by an oxygen-containing gas mixture may not be suited for treating high-fat foods because the ROS produced may increase oxidation of the food products (Sharma et al.,2018).

2.3 Bioactive Packing - Probiotics

Edible coating provides a protective barrier against physical and mechanical damage, as well as creating a controlled atmosphere and acting as a semipermeable barrier for gases, vapor, and water, edible films and coatings can be beneficialfor extending the shelf life of the product and also helps in maintaining nutritional and sensory qualities(Pop et al.,2019; Jemima et al., 2021; Hanumantharaju et al., 2020; Hanumantharaju et al., 2021).It is a fresh approach to the concept of functional foods, which suggests that any food that can deliver a health benefit in addition to the standard nutrients it contains is functional. Bioactive packaging not only serves as packaging technology that maintains or improves the quality and safety of packaged goods, but it also has a direct impact on consumer health by generating healthier packaged meals. The use of bioactive packing materials will assure storage and, eventually, release (Pavli et al.,2018).

Bioactive packaging materials will protect the bioactive agents and eventually release them into the food product. Bioactive food packaging methods may provide customers with health benefits. Bioactive packing materials may contain (bioactive) substances that are later released into the food product. In the case of probiotic-containing edible coatings, the release is not even required because the coating is intended to be consumed with the food (Pavli et al., 2018).

Naturally derived ingredients, such as polysaccharides, proteins, and lipids, or a combination of these elements, are used to make edible films and coatings. These films and coatings also allow for the incorporation of various functional elements such as nutraceuticals, antioxidants, antimicrobials, flavoring agents, and coloring compounds. Living microorganisms can also be included into films and coatings.
(Guimaraes et al.,2018).

Application

Materials having film-forming capabilities can be used to create edible films. Hydrocolloids, lipids, and composites are the three types of components employed in the manufacture of edible films and coatings. Other chemicals include

Plasticizers and emulsifiers are additives to film-forming solutions that improve mechanical qualities or increase stability when lipids and hydrocolloids are mixed. Plasticizers are commonly utilized in the production of edible films and coatings, especially when polysaccharides or proteins are used as ingredients. Plasticizers are lowin molecular weight which are helpful to low glass transition temperature of film-forming materials when added.

Polysaccharides and proteins comprise the hydrocolloids category. Polysaccharides such ascellulose derivatives, starch derivatives, pectin derivatives, chitosan, seaweed extracts, and galactomannans can be used in edible films or coatings. Polysaccharide films and coatings are good oxygen, odor, and oil barriers with good mechanical qualities.

Gelatin, maize zein, wheat gluten, soy protein, collagen, and casein are all proteins utilized in edible films and coatings. As the solvent evaporates, protein films are produced.

The material used to make edible films and coatings may be heterogeneous. It is possible that an edible film consists of a blend of polysaccharides, protein and/or lipids. Such a film is defined as a composite (Bourtoom 2008). The aim of producing composite films is to adjust the characteristics of the film in order to use it for a specific application. Since each individual coating material possesses some unique, but limited functions, a combination of different materials can be more effective
(Pavli et al.,2018).

Mode of action

Antimicrobial

Probiotic microbes in edible coating could prevent food from harmful germs, increasing food safety. They may also suppress spoilage microbes, thus extending food shelf life. Lactobacillus sakei probiotic strains were embedded in a sodium caseinate-based film via direct integration in the film-forming suspension or spraying on an already-formed film. The film and its non-probiotic lactobacilli counterpart were put on plates of tryptic soy agar containing fresh beef slices contaminated with Listeria monocytogenes. The probiotic strain boosted its cell density by one log cycle during four days of incubation on plates. During the 12 days of storage, L. monocytogenes decreased (3.0–3.6 log cycles).

The amount and type of antimicrobial compounds produced by LAB during fermentation will be determined by the LAB strains, culture medium composition, and growth circumstances (Ammoret al., 2006). When added directly to a food product, the efficacy of antimicrobial chemicals produced by LAB can be affected by several conditions. Antagonistic yeasts can also be employed to inhibit the growth of molds in cereal grains, resulting in a reduction in mycotoxin contamination (Guimaraeset al.,2018).

Limitation

- Regulation issue: More concerns about law arise when edible films and coatings contain probiotics. There is no regulatory framework in the European Union (EU) that defines probiotic bacteria or the food category "probiotics," and the regulation is relatively conservative. Even while the majority of probiotic bacteria have been used as safe food components and their safety has not been disputed, a favorable assessment from EFSA is required for European Commission permission under EC No. 1924/2006 regulation (No, R. (1924). 2006).
- Edible coating molecules can affect flavor, be vulnerable to rapid degradation, interact unfavorably with other constituents of the food matrix, and have restricted solubility (Quiroset al.,2014)
- Incorporation of living microorganisms in edible films and coatings introduces new challenges; they must remain viable in sufficient concentrations to exert probiotic or antimicrobial activity while not altering the

barrier and mechanical properties of the film or coating and without changing the sensory properties of the food product (Guimaraeset al.,2018).

CONCLUSION

Hundreds of millions of tonnes of food are wasted globally each year, necessitating the development of technologies to reduce waste by extending shelf life, as fruits and vegetables are perishable by nature. This study looked at the latest trends and methodologies for extending the shelf life of fruits and vegetables, as well as their benefits and drawbacks, in order to help identify, design, and optimize the best decontamination process to reach the desired level of decontamination.

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