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Beyond the Harvest: Innovations Securing Our Food Future- An Overview

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Abstract- From past few decades, besides the authentic and traditional processes of harvesting, some new advanced post-harvest chemical and physical treatments (such as nanotechnology, modified atmospheric storage, cold chain logistics, active packaging, pulsed electric field, dipping, cold plasma etc) and certain biocontrol approach have been introduced to preserve the shelf life, maintain the nutritional value and safety of freshly harvested products. Furthermore, the implementation of Artificial Intelligence, sensor-based monitoring, and sustainable packaging solutions aims to transform the post-harvest technology towards much higher efficiency, thereby having less environmental impact. This paper contains information and studies on the topic of advanced post-harvest technologies to preserve the food quality and reduce losses and waste in fresh produce.

Keywords- advanced post-harvest technologies, cold chain logistics, dipping, nanotechnology, sensor-based monitoring.

I. INTRODUCTION:

Agriculture plays a very crucial role in terms of global food security, yet a substantial portion of the harvested yield never reaches the consumers due to the “Post-harvest” losses. As per the “Food and Agriculture Organization (FAO)”, approximately one-third of the food produced globally is wasted annually, with the developing countries suffering the brunt of losses during post-harvest handling, storage, and transportation (Stuart, T. 2021). The food quality can thus be defined as a combination of several physico-chemical characteristics (features, flavour, consistency, and nutritive value) that have a significant contribution in shaping a consumer’s attitude or perception of a certain product (Lin et al., 2023). The quality of these fruits and vegetables is substantially grounded on the judgement of various outward characteristics (proportions, structure, colour, buff, stiffness, consistency, and flavour) and certain intrinsic factors (physico-chemical and microbial) dealing with nutritive attributes, health-security, and sustainability (Aghababaei et al.2025)

Cultivated crops are very actively engaged in chemical processes and get spoiled very quickly, hence are extremely perishable (Singh et al.2021). Their quality degrades mainly due to the processes of aging and maturation, which are often linked with the initiation of spoilage, causing microbes and other desired occurrences, which need to be managed to conserve the nutritional attributes, standards, and improve shelf-stability of the product during storage (Zhao et al.2022). Besides, high moisture content and the presence of various nourishing factors can also lead to the growth of these pathogens (Snyder et al.2024). Fruits and vegetables with good nutritional and sensory attributes generally have a higher economic value. Thus, improper conservation techniques, apart from creating hefty losses in the aspect of nutrition and attributes, can also cause systemic economic fallout (Kaur et al.2024). According to the “The Food and Agriculture Organization (FAO)” (Figure 1), overall 44% of losses are incurred in industrialised countries and 40% occur in underdeveloped countries (Nicastro et al.2021)

II. POSTHARVEST STRATEGIES TO EXTEND THE SHELF-LIFE OF FRUIT AND VEGETABLES

1. Physical Treatments

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Innovative technologies can decrease the nutritive losses, enhance consumer adequacy, elevate food quality, and increase shelf-life and goodness, promising the complete deprivation of chemical byproducts in the reused product, combined with a curtailment in the environmental impact (Lohita et al.2024). From these arising techniques**,** high hydrostatic pressure(HHP), pulsed electric fields(PEF), and cold plasma have been used to extensively to decrease the bacterial cargo, therefore helping to conserve the originality and qualitative attributes of fruit and vegetables (Chen et al.2024). However, these methods show multitudinous positives and negatives that have begun to be delved to reach the required criteria by embracing cost-effective styles.

- *High Hydrostatic Pressure:* High Hydrostatic Pressure (HHP), also known as High-Pressure Processing (HPP), is a non-radiative preservation method that uses very high levels of isostatic pressure, typically ranging from 100 to 600 MPa (megapascals), applied uniformly in all directions through a liquid medium (usually water). It is mainly required for sterilization and for enzyme degradation. Several reports depict that HPP majorly affects the bacterial or microbial count and it also dominates the functionality of proteins similar as enzymes and tissue structure. HHP application has its effect on different unrefined horticultural produce, whole yield, and juice, thereby demonstrating great effectiveness in enhancing the food safety aspects and in maintaining quality (Pérez-Lamela et al.2021).
- *Pulsed Electric Field:* This technique is mainly used on liquids, partial-solids and solid foods which includes fresh fruits, vegetable smoothies and juices (Roobab et al.2022). This particular method has minimal heat damage hence retains vitamins (C and B complex), carotenoids and phenolics better than thermal processing. Besides, this method effectively inactivates bacteria, yeasts, and molds while preserving the sensory quality and the time required for the entire treatment is comparatively shorter as compared to traditional heating. This process basically uses short bursts of very high voltage current pulses applied to the food sample placed between two electrodes.
- *Cold Plasma:* Cold Plasma (CP), is an emerging post-harvest technology that uses partially ionized gases containing a mixture of electrons, ions, free radicals, reactive oxygen/nitrogen species (ROS/RNS), UV photons, and charged particles. This technique is used in the whole and minimally processed food industry as a novel methodology used to handle the proliferation of microbes with the aim of replacing the traditional sanitary methods while preserving the nutritional and antioxidant attributes of the food product (Domonkos et al.2021). This also reduces pesticide residues on leafy vegetables and fruits and also controls insect infestation, reduces mycotoxin contamination, and enhances seed germination.

2. *Chemical Treatments*

Post-harvest chemical treatments are mainly utilized for the delay of spoilage, minimization of decay, control of physiological disorders, and extension of shelf life of perishable produce. The treatments consist of the use of natural or synthetic (artificial) chemicals by the process of dipping, spraying, fumigation, or coating. These treatments involve the use of natural or artificial (synthetic) chemicals, either by dipping, spraying, fumigation, or coating. While physical methods (like High Hydrostatic Pressure, Pulsed Electric Field, cold plasma, and controlled atmosphere storage) are gaining attention, the chemical treatments also play a very important role, especially in emerging nations where cost-effective solutions are essential.

- *Edible Coatings and Films:* Edible packaging is produced in the form of edible coatings or edible films. Edible packaging materials can be applied directly on the surface of food materials and act as a barrier to gases, moisture, solutes, etc (Kocira et al.2021). In post-harvest handling, edible films and coatings are frequently used in combination with plant-based essential oils and natural antimicrobial agents. For example, use of chitosan, a biopolymer, can be used to increase the shelf-life and reducing the microbial contamination of the food materials. As these coatings are

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biodegradable, they increase the environmental sustainability and also widely accepted by consumers. With the antimicrobial properties, they stand out as strong replacements for synthetic preservatives. The new developments in nano-technology and multi-functional films, these coatings are expected to become a key part of a sustainable future in the aspect of food preservation.

- *Fumigants and Controlled Chemicals and Fumigants:* Among the crops that are most susceptible to insect damage, spoilage caused by microorganisms, and contamination with mycotoxins while in storage, come grains, legumes, nuts, and dried fruits. To preserve these food products and prevent such unwanted losses and enable longer-term storage, the utilization of controlled chemicals and post-harvest fumigation is among the best strategies. Fumigants are substances that exist within the gaseous state at a prescribed pressure and temperature and can penetrate through commodities in bulk and kill pests (Stejskal et al.2021). Some of the other controlled chemicals include sanitizers, ozone, and other gaseous substances that assist microbial control and quality preservation

III. CONCLUSION

Post-harvest technology plays a significant role in ensuring global food security by ensuring the crops developed through hard work reach the consumers in high-quality, nutritious, and safe form. These are very different methodologies involved here—from the physical treatments like high hydrostatic pressure (HHP), pulsed electric fields (PEF), and cold plasma, through the controlled atmosphere storage, chemicals, and fumigation, and the edible coatings—each one of them emphasizes inter-disciplinary collaboration for addressing these challenges.

Physical treatments (like HHP, PEF, cold plasma, and controlled atmosphere storage) have been effective for enhancing the quality and safety of the product and, thus, the shelf life. In short, the combination of these technologies exemplifies innovation within the agricultural and food arena with an emphasis on the interests of the consumers. In contrast, the chemical strategies (like the films and coatings that are edible, the fumigants, and the regulated chemicals) remain dominant, in particular within the scale industries and the resource-poor contexts, although there is a greater focus on the usage of safer and degradable chemicals. In the final reckoning, the utilization of the foregoing post-harvest technologies lowers the loss and waste of the food, increases the farm earnings, facilitates the trade globally, and directly advances the United Nations Sustainable Development Goals (SDGs) of zero hunger, responsible consumption, and climate action.

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