



EXPLORING THE LATEST TECHNOLOGICAL INNOVATIONS AND THEIR IMPACT ON FOOD PRESERVATION AND SAFETY

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Abstract:

Introduction: Overview of the 21st IIR International Cold Congress, highlighting the pivotal role of Commission C2 in advancing food science and engineering globally. Emphasis on the dissemination of technological advancements for the betterment of humanity.

Previous Conferences and Discussions: Insights from past IIR-sponsored conferences focusing on postharvest techniques, cold chain logistics, and comprehensive reviews of quality, safety, and environmental considerations.

Crucial Role of Refrigeration Technology: Discussion on the vital role of refrigeration technology in promoting food security, reducing foodborne diseases, and fostering development, particularly in developing nations facing significant handling challenges.

Ripening Process and Quality Parameters: Examination of the ripening process of fruits and vegetables, along with the assessment of quality parameters such as visual appearance, texture, flavor, and safety.

Consumer Preferences and Concerns: Analysis of evolving consumer preferences and concerns regarding plant-based foods, emphasizing the growing awareness of freshness, safety, and nutritional content.

Cold Chain Management and Traceability: Maintaining cold chain integrity and ensuring traceability throughout the distribution process is crucial to uphold product quality and safety standards.

Challenges and Solutions: Exploration of challenges related to microbial flora, foodborne pathogens, and the effectiveness of conservation techniques, alongside discussions on packaging's role in preserving food quality and safety. Integration of barcode technology for enhanced traceability.

Research Needs and Future Directions: Identification of research needs and future directions, including the development of rapid pathogen detection methods, enhancement of sanitation programs, and exploration of innovative techniques to improve the quality and safety of refrigerated food products.

Conclusion: Emphasis on the importance of ongoing research and development efforts to address current challenges and meet the evolving needs of the food refrigeration industry.

Keywords: Food Refrigeration, Quality and Safety, Cold Chain Management, Consumer Preferences, Technological Advances, Food Security

INTRODUCTION

On the 21st International IIR Event Cold Senate, the Commission C2, and the IIR commission responsible for food science and engineering has 76 papers; the authors of the papers came from a multitude of the 61 members of the IIR and non-member countries. The work presented aims to disseminate technological advances in food refrigeration and its applications as widely as possible. We are confident that the work presented at the conference will contribute to rapid advancements in food science and engineering worldwide for the well-being of humanity.

Table 1: References from the 21st IIR International Cold Congress

Reference	Details
Bhokarikar & Athmaselvi, 2024	Bhokarikar, A., & Athmaselvi, K. (2024). A review of advances and trends in postharvest techniques, cold storage, transportation, and distribution consisting of fresh fruits and vegetables. The IIR Conference offered her a presentation., Arid Agriculture University, Rawalpindi, Pakistan.
Chao, Hu et al. 2024	Chao, Y., Hu, J., et al. (2024). Factors influencing the quality of plant-based food items: A consumer perspective. Presented at the 21st IIR International Cold Congress.

Table 2: Additional References

Reference	Details
Kader2	n.d. Kader, A. A.'s work. Things that have an impact on the quality of the fruits and vegetables. Research and Information Center for Postharvest Technology at the University of California, Davis? Obtained from the [link]
Kays3	Kays, S. J. (n.d.). Postharvest physiology of perishable plant products. A United Nations organization that focuses on food and agriculture. Retrieved from [link]

Advances and trends in postharvest procedures, cold storage, transportation, and distribution in addition to using fresh fruits and veggies ornamental plants were discussed at recent conferences that were funded by the Importance of Research (IIR) at Arid Agriculture University in Rawalpindi (Pakistan) in the year 2022. The requirements for the environment, as well as the quality and safety of food products, were also examined (Bhokarikar & Athmaselvi, 2024). This specifically focused on the consumer's point of view. Because it plays such an important part in ensuring food security and health, as well as in dramatically lowering the incidence of foodborne infections, refrigeration technology is essential to the development and modernization of a nation. Without it, it is impossible

to achieve these goals. It is of the utmost importance, especially in developing nations, to advance food science and technology at the beginning of the new millennium. The International Institute of Food Research (IIR) plays a pivotal role in the dissemination of the necessary information.

Improving how frozen and refrigerated goods are handled in developing nations is the current problem. As is common knowledge, the IIF plays a significant role in risk management by providing technical assistance and expertise in good refrigeration practices to all parties involved in refrigeration, including decision-makers, public authorities, industrialists, researchers, educators, food producers, and refrigeration professionals. Enhancing the quality of fruits and vegetables requires a multidisciplinary, consumer-focused approach from food engineers and academics. Many factors determine the quality of food items, the most significant of which is safety. Other factors include color, texture, flavor, and nutritional content. The primary factors that customers consider when assessing the quality of plant-based food items are color and look. Kader² and Kays³ point out that flavor, aroma, crunch, and juiciness are also decisive attributes for buyers of fresh fruit and vegetables (Chao, Hu et al. 2024).

II. RIPENING OF FRUITS AND VEGETABLES AND QUALITY CRITERIA

The maturity of a product of plant origin is defined by professionals in the agri-food sector as the stage of growth following the harvesting and processing of the product, the point at which the product's quality will be at least at the minimum acceptable level for the end customer in order for the product to be called mature. This concept is based on the assumption that the stage of development can be effectively measured and that there are methods available for determining the level of maturity.⁴ Senescence can be thought of as the beginning of the ripening process, which occurs during the final stages of maturity. The intracellular organization starts to take shape over the course of development. Degradation, a reduction in the gas permeability of cell membranes, which leads to anaerobic respiration and the buildup of toxic substances in the surrounding environment (such as ethanol, acetaldehyde, and ethyl acetate) will ultimately lead to the death of the cells. The cell. The biochemical changes that occur during senescence not only encourage the development of microorganisms but also result in the loss of natural immunity (Dharini, Ramanan, et al. 2024). Not only does this make plant products more susceptible to microbial infections, but it also takes place at this time.

The quality of fresh commodities is determined by the collection of a range of biophysical and biochemical variables that are combined together. There are a number of features, attributes, and properties that influence the nutritional value of the product or the pleasure that is delivered when consuming it. The relative relevance of each quality parameter is determined by the type of product and the ultimate application of the product. Visual appearance (including the lack of faults from cold damage), texture, flavor, nutritional content, and safety are the primary criteria for determining quality. According to Dharini, Ramanan, and others (2024), each of these metrics includes a collection of features (attributes) that are helpful for evaluating products in comparison to quality standards, selecting them for varietal improvement programs, and evaluating their responses to environmental conditions and treatments after harvest.



Finding and quantifying the most important factors is the most challenging aspect of establishing the quality of a product that is derived from plants. Between the stage of maturity and the edibility of fruits and vegetables, there is a differentiated quality that can be observed. Despite the fact that a fruit may have attained maturity, it will not realize its full potential in terms of flavor until it is entirely ripe, which may necessitate ripening once it has been harvested. On the other hand, perfect ripeness is directly proportional to perfect edibility for the majority of vegetables. What is meant by the phrase "shelf life" There is a term known as "shelf life" that refers to the duration of time that a product is able to maintain its quality at a specific level under specific storage conditions. The reduction of the amount of food that goes bad is the major objective of maximizing the handling and shelf life of fresh fruits and vegetables that are not climacteric. This is accomplished by slowing down the rate of metabolism. To the contrary, the ripening process for climacteric items needs to be tuned according to the final use (whether it is consumed in its fresh or processed stage). Based on sensory qualities and microbiological safety, the optimal stage of maturity of a product at the time of harvest is the primary factor that determines its final quality and shelf life (Kaur, Somasundram et al. 2024). This is the main parameter that determines the product's shelf life.

In today's world, customers have a tendency to watch what they eat and take responsibility for their diet. Consumers now have access to the topic as a result of the adoption of contemporary methods and the dissemination of the findings of studies concerning nutrition and health. At this point in time, consumers are considerably more aware of the connection between food and health, and they are adequately informed to make decisions regarding their diet. Since the market for refrigerated items is rising additionally, the shelf life of these products is gradually growing, while the heat treatment of products and the substances that they include is gradually lowering.. This is being done in order to satisfy the demand of consumers for products that are fresh, perfect, and delicious. On the other hand, the conventional purchasing criteria of flavor, simplicity of use, and price remain to be the primary driving forces behind recurrent purchases (Mahmood, Muhoza, et al. 2024).



Consumers are increasingly concerned about the product quality and safety of plant-based foods and greatly emphasize freshness when purchasing refrigerated products. The most common concern Pesticide residues on plants are the most concerning aspect of food safety, followed by improper handling and cleanliness. Because of this, several stores assure their customers that their products comply with the limits of pesticide residues imposed by law or contain no residue, and more and more Organic fruits and vegetables appear in supermarkets. However, consumers are also attracted by a healthy diet in terms of checking their diet of fat, cholesterol, sodium, and both macro- and micronutrients, as well as their composition Community. Other research has also been conducted on the subject. Food security is defined as "access for everyone, at any time, to sufficient nutrition to lead an active and healthy life," as stated by Mahmud, Valizadeh, and others (2024). This definition comes from the CNMap project. The construction of profiles that can be used to determine whether or not a community is at danger with regard to food security or other nutritional issues is made possible according to this definition.

Fresh fruits and vegetables, in addition to being relatively inexpensive, include a wide array of compounds that have a tremendous amount of nutritious value. Vitamins, minerals, fiber, and other substances that the body is unable to make on its own at this stage are included in this category of substances. Fruits and vegetables are the primary sources of antioxidants in the diet, and there is a growing interest in learning more about the nutritional value of antioxidants. Antioxidants offer a number of health benefits. The ability of anthocyanins and other phenolic compounds to not only neutralize free radicals but also possess antioxidant characteristics makes them extremely valuable resources (Sandupama & Wansapala, 2024).

Food products have become very popular since the appearance of new eating habits such as snacking or nibbling, and due to the availability of products all year round and a tendency to want a healthy diet and to monitor calorific intake. The product market has grown considerably in terms of when it comes to the quantity and range of products that are available to customers. Because of this, there has been a growing need for products requiring less preparation, which is more in line with current consumer lifestyles. Besides convenience, consumers perceive fresh-cut fruits and vegetables as cheap due to the limited amount of wastage and their high quality (Sharma, Perera et al. 2024).

The cooling and refrigeration industry places a significant emphasis on the thermophysical characteristics of food products. In order to compute the rates at which fruits and vegetables are heated and cooled, it is necessary to have accurate data on different thermal parameters. In order to determine the heat conductivity of a wide variety of products, a number of researchers studied them. In the majority of food engineering applications, having a solid understanding of thermal characteristics is a factor that is absolutely necessary. Establishing these qualities by the use of empirical formulas for a certain product composition and temperature is one of the most prevalent ways. Engineers typically ask for a rapid estimate of the qualities in the event that they are unable to conduct thorough experiments. Quite recently, software has been created that can determine thermal properties by employing empirical relationships as a function of temperature and composition respectively. (Suri, Bhinder et al. 2024).



III. COLD CHAIN, TRACEABILITY AND QUALITY

Therefore, regarding the preservation of temperatures and the evaluation of the performance of equipment for the various phases of the cold chain, ranging from warehouses to furniture sales, regulations have been put into place at the European level and in many countries. These regulations have been implemented. Harmonization has taken place in European directives concerning the temperature of frozen products and during the primary stages of the production and distribution chain on a global scale. This industry is one in which laws and standards of practice play a key part in the overall process. For instance, they propose that loading and unloading be done quickly, that loading docks be enclosed and equipped with air conditioning systems, and that consumers transport their

goods using insulated or chilled bags. We are able to name air temperature measuring equipment as one of the tools that show the functioning of refrigeration appliances. These instruments include temperature recorders for warehouses and refrigerated trucks on the one hand, and thermometers for small cold rooms, sales furniture, and refrigerators on the other. According to Chao, Hu, and others (2024), by continuing to employ these technologies, the cold chain between the producer and the consumer would be improved, which would ultimately result in improved food quality.

There are frequently multiple stages of storage and transportation that occur before consumption in the food distribution chain, and traceability has emerged as an important notion in today's world. Every participant in the cold chain is required to have access to the time-temperature history of the product by way of the operator who came before them, and they must present the required information to the link that is provided below. When loading and unloading take place outside of temperature-controlled circumstances and after the product has been sold to the consumer, the temperature of the product may change from one stage to the next. Thermometers, temperature loggers, indicators, and time-temperature integrators are all examples of devices that can be used to incorporate traceability.. By making use of these techniques, it is possible to acquire a more in-depth grasp of the time-temperature history that takes place along the cold chain. However, it is impossible to determine the temperature history of the product from the time it was manufactured until the time it was delivered. An example of a simulation can be found in Figure 1, which pertains to the distribution chain of freshly cut fruits and vegetables. However, in reality, we frequently record the temperature of the air, which does not correspond to the temperature of the thing that is being discussed. The Hazard Analysis Critical Control Point (HACCP) system, which is designed to ensure the safety of fresh produce, has been the focus of a limited number of research that have analyzed the refrigerated transit as a critical control point. These studies have been conducted within the context of the HACCP system. When it comes to the foundation of a HACCP equivalence program, the amount of scientific evidence that lies at its core is relatively small. In the future, public authorities will be forced to adopt food safety strategies that combine existing regulations covering food restrictions, product temperature, and equipment performance testing with new techniques, as stated by Dharini, Ramanan, and others (2024). These strategies will be required to be implemented. The auditing of HACCP systems that have been built by firms, the communication of risks, and the transmission of information to customers are all examples of these innovative techniques.

A crucial component in the cold chain is the maintenance of temperature during the transportation process. This helps to guarantee that fresh produce is of high quality and reduces the danger of microbiological illnesses, particularly for fruits and vegetables that have been newly cut and individually packaged. An effective way of control for the majority of infections is to keep the temperature at a low level. In addition to maintaining the proper temperature, the container must be kept clean during the whole process of transportation and distribution. It is imperative that ducts are devoid of any particles that can hinder the flow of air and prevent the circulation of cooled air towards the load. One more thing that is necessary in order to guarantee both quality and safety is the precise monitoring of cold chain control and history. (Kaur, Somasundram, et al. 2024) The technique that is necessary to monitor the performance of a refrigeration system while it is being transported has been simplified by modern monitoring stations, and certain indicators show when a critical point has been exceeded.

IV. COLD CHAIN AND SECURITY

These days, food products almost seldom originate from the same country or source. Instead, they are typically the result of a combination of raw materials sourced from a number of various countries and a variety of production techniques. According to Mahmood, Muhoza, and others (2024), it appears to be required to create and implement specific HACCP processes for every production facilities. The reduction of the flora that is responsible for microbiological deterioration is the most important goal to achieve in order to retain the quality of vegetables. This level of flora is responsible for both the

rotting of the product and the health hazards that are associated with it. Numerous elements, including temperature, time, and pressure, have been proven to play a role in the infiltration of pathogens into fruits and vegetables. These infiltrations can occur through cracks, crevices, and intracellular spaces. Due to the fact that there is a growing interest in raw or freshly cut food goods, the production environment for four different ranges is changing, new products are being introduced from within its range, and there is a failure to follow basic practices for handling fresh produce, the prevalence of foodborne infections is not going to reduce and may potentially increase. The metabolic potential of a raw or freshly cut product is the primary factor that determines whether or not a pathogen will be able to survive and develop on or in the product. This potential affects the ecological factors of the product as well as those that are imposed during production, distribution, and preparation prior to consumption (Mahmud, Valizadeh, et al. 2024).

Over time, there might be a considerable shift in the spectrum of infections. *Listeria monocytogenes*, *Aeromonas hydrophila*, *Andguinea pigs*, and *Clostridium botulinum* are among the most known examples of psychrotrophic pathogens. These pathogens are able to sustain their infectious capacity even when exposed to low temperatures. For the most part, they are found in vegetables. *Escherichia coli* O157:H7, *Salmonella*, *Yersinia enterocolitica*, *Campylobacter jejuni*, and other viral and protozoan bacteria are also frequently found in vegetables. These pathogens are usually associated with vegetables. In order to match the expectations of consumers regarding the freshness and safety of fruits and vegetables, the industry must employ high-quality processing procedures and precision. This is because the amount of bacteria that are usually found in untreated products ranges between 10⁵ and 10⁷ CFU/g. (Sandupama & Wansapala, 2024) The application of a wide variety of conservation strategies, the majority of which operate to prevent or limit microbial development, can considerably reduce the likelihood of a variety of microbial deterioration forms occurring.



When it comes to horticulture items, it is well knowledge that chlorine washing at concentrations ranging from 100 to 150 parts per million (ppm) is an efficient method for lowering the quantity of bacteria present. It is anticipated that in the future, there will be a greater concentration of chlorine consumption. Byproducts of the chlorination process do, in fact, provide the possibility of hazards being introduced by chlorination. Disinfection occurs. It has been claimed that works have been done that demonstrate the connection between these dangers and the development of trihalomethanes (THM). The chlorination of water results in the production of THMs, which are compounds of natural organics that are known to have negative consequences, such as toxicity to the liver and kidneys. The

addition of ammonia during the chlorination process transforms chlorine to chloramines, which is one method for lowering the total hydrocarbons (THM) content of the chlorine treatment. Chloramines, in contrast to chlorine, do not create THMs when they combine with organic hydrocarbons in water. To keep the same level of security, however, the amount of disinfectant that is used should be increased. This is due to the fact that chloramines are less efficient as agent disinfectants. It is therefore required to carry out the necessary tests in order to optimize system performance and THM control before switching from chlorine washing to chloramine washing (Sharma, Perera, et al. 2024).



A reduction in the growth of microorganisms as a result of the antimicrobial activity of high CO concentrations may be linked to the improvement of the sensory characteristics of lettuce leaves that come into contact with greater levels of oxygen² in comparison to the controls. In point of fact, the presence of oxygen at a pressure that is higher than the pressure of the atmosphere makes it possible to employ CO concentrations that are excessively high in packing without affecting the edible quality of the lettuce. Therefore, the correlation between high levels of oxygen and carbon dioxide can be regarded as the most important factor in determining the performance of this new spectrum of lettuce preservation techniques (Bhokarika & Athmaselvi, 2024).

UV-C radiation is one example of a technology that can be used to inactivate microorganisms by having a major impact on their physiological processes or cellular structure. This can be accomplished through the disruption of cell membranes, the breaking of DNA strands, or the mechanical deterioration of the cell envelope. The 'Lollo Rosso' and 'Red Oak Leaf' varieties of red lettuce are able to be properly preserved from their range by utilizing ultraviolet C (UV-C) radiation, in conjunction with refrigeration and changed atmospheres. In comparison to the control, the product that has been treated with UV-C has a lower number of psychotropic microbial communities, coliforms, and yeasts. This is the case even though the lactic acid bacteria appear to be more resistant. Each stage of handling, processing, distribution, and retailing must be carried out using a systems integration that is referred to as a "systematic approach," in which each stage is considered in conjunction with the others. This integration is required while producing a product range. It was brought to everyone's attention that solving problems with food security requires taking a comprehensive and coordinated strategy. Along the whole supply chain, from the harvesting of raw materials to the consumption of freshly cut fruit, it is vital to conduct rigorous and systematic monitoring of hygiene measures. Furthermore, the air treatment criteria that are based on the "clean room" concept are extremely important (Chao, Hu, et al. 2024). In particular, the entire clean area must be insulated and equipped with an air conditioning system that maintains a temperature that is lower than ten degrees Celsius.

V. PACKAGING

As a result of the several roles that it serves, the importance of packaging in the food sector is becoming more widely acknowledged. When a product is packaged in a way that is well-designed, it should be possible to extend the shelf life of the product by delaying the degradation of its quality and ensuring that it is safe to consume.



In modified environment packaging, it is possible to lower the danger of fermentation by employing holes or micro-perforations. However, this approach also enhances the chance of product recontamination, which adds to the risk of contamination. The development of perforated modified environment packaging for whole fruits and vegetables has been the subject of research in a number of studies that have been conducted in recent historical times. Currently, we are having a conversation about a range that is designed to mitigate the undesirable effects that are brought about by temperature shifts within product palettes. A particular emphasis is being placed on the development of models that are able to predict the permeability of these films, as well as the production of a coextruded film that may be used for the packaging of fruits and vegetables that are either whole or completely sliced. In order to establish the oxygen permeability and carbon dioxide (CO₂) that are required to achieve an optimal balance of the environment inside the packaging, it is necessary to validate the integrated mathematical models. This is what is required in order to determine the oxygen permeability.

In addition, it is essential to do research into the influence that temperature shifts throughout the distribution chain have on the respiration rate, activation energy, and permeability of the film over the whole distribution chain. The creation of safe packaging that may be used in an environment that has been modified requires special attention to be paid to extremely high or extremely low quantities of oxygen.² Sandupama and Wansapala (2024) claim that methods that involve the application of moderate vacuum could be useful for the individual packaging of things that fall into the fourth range, either on their own or in conjunction with antioxidants. This is due to the fact that these methods involve the use of moderate vacuum.

Within the food business, which includes the market for fruits and vegetables, the application of barcode technology has been the most significant development that has taken place over the course of the previous few decades. This technology has been embraced by more than 120 countries over the course of the last quarter of a century, and it has developed into an essential tool for the supply chain of the global market as well as for doing business online. One of the most important factors that contributes to the traceability of each product is the use of barcodes. Also, e-markets are establishing online purchasing in the retail sector, which can be done either at home with electronic pens or on-site with computers (Mahmud, Valizadeh, et al. 2024).

This can be done in either of these two locations. It is for the purpose of delivering an additional service to individuals that this action is being taken. It is possible that the barcode may be easily modified to convey information that is exceedingly helpful (Mahmood, Muhoza, et al. 2024). These are all things that need to be looked into. All of these questions and concerns need to be investigated. The necessity of conducting research. Throughout the twenty-first century, numerous pre- and post-harvest treatments have been invented and successfully implemented. These treatments are designed to maintain the quality of fruits and vegetables that have been picked and to make it possible for them to be transported to marketplaces that are located closer to the source of the harvest. Utilization of intermodal terminals and transportation that takes place in an environment that is either regulated or changed is becoming an increasingly significant aspect of the transportation industry. The problem that we are currently facing is to enhance the visual look of fruits and vegetables while simultaneously optimizing their levels of safety and characteristics, such as their chemical composition and the quality of their nutraceuticals. It is necessary to provide proof from the scientific community that demonstrates the connection between diet, nutrition, and physical activity on the one hand, and chronic diseases on the other side (Kaur, Somasundram, et al. 2024).



The creation of novel, speedy, and precise technologies for the detection of infections and the harmful metabolites that they produce, such as mycotoxins, is a vital component of an integrated approach for the improvement of food safety. In addition, there is a huge demand for procedures and processes that are standardized, dependable, fast, and cost-effective in order to prevent fraud and ensure that consumers have confidence in the quality and safety of food products.. In addition to the HACCP system, a substantial amount of time and resources must be allocated to the development and implementation of sanitation programs such as Good Manufacturing Practices, systematized sanitation programs such as operating procedures standards for hygiene (Sanitation et al.), and microbiological environmental analysis programs (Dharini, Ramanan, et al. 2024). There is a need for these programs to be implemented in the real world. These are all instances of sanitation initiatives that need to be implemented, and they are all different.

Additional research needs to be carried out in order to establish the relationship between pre-harvest and post-harvest treatments. There is a need for extra work to be done in order to assess the potential hazards and the limits of effectiveness of the new postharvest processing technologies for fresh whole fruits and vegetables, as well as those of the four ranges. This is a necessity since there is a need for additional work to be done. On the subject of these technologies, the biological control of microbial antagonists of the microorganisms that are accountable for postharvest losses can be considered to be of the utmost importance.

With the intention of taking it to market, it is necessary to develop alternative physical procedures that can reduce the amount of mold and cold deterioration that occurs in whole fresh fruit and four different ranges. Using heat treatments such as hot air, hot water soaking, or hot water spraying, in conjunction with modest doses of fungicides and UV-C radiation, should be the primary techniques (Chao, Hu, et al. 2024).

A tool that shows promise is the utilization of high amounts of oxygen. However, there are certain factors that need to be clarified, such as how the development of different kinds of bacteria, mold, and human pathogens is affected by high concentrations of oxygen, either on their own or in combination with high amounts of carbon dioxide. In the years to ahead, the O₂ rate combination at a pressure that is higher than the atmospheric pressure and high concentrations of CO₂ will become an intriguing topic of research. This combination will have an effect on the texture, flavor, and nutritional quality of products. A fascinating alternative to chlorination is ozone, which is a gas that is permitted in certain nations for use as a postharvest treatment when it comes into close contact with fresh food. In light of recent recommendations made by a group of experts at the Food and Drug Administration (FDA) in favor of classifying O₃ as a safe disinfectant for food products, the industry was able to independently assert that this method guaranteed food safety if it was applied in conjunction with good production practices (Bhokarika & Athmaselvi, 2024).

Both new modified atmosphere packaging that is used with polymers (such as antimicrobial polymers that contain a porous substrate covered with crystallizable polymers with side chains, an O₂ emitter² and CO neutralization devices² or C₂H₄, or moisture absorbers) and improved edible films (such as those combined with antioxidants) have a significant amount of potential for application potential. Using these materials could help prevent anaerobiosis and minimize respiration rate, ethylene emissions, browning, and mass loss.

As a result, unwanted changes in sensory quality could be mitigated, mechanical characteristics and handling could be improved, and microbial growth could be controlled. Every single one of these potential uses needs to be investigated separately for every single category of product. In today's world, techniques of genetic manipulation are utilized in order to enhance the characteristics of a product, such as its color, scent, flavor, and taste. It was the FLAVrSaVR tomato, which had decreased polygalacturonase activity, that was the first transgenic food product ever created. Despite this early success, there are a few crucial aspects that control postharvest quality that have not yet been examined and need to be explored. These parameters include resistance to cold, extension of shelf life, resistance to viruses, and other similar characteristics. There is still a significant amount of work in this area, and recent advancements in functional genomics ought to bring to light genes that are capable of being changed (Suri, Bhinder et al. 2024). This is something that need to be done.

In addition to promoting the consumption of fresh fruits and vegetables, particularly those with a tough skin or seeds, it is anticipated that the four varieties will offer solutions to specific problems and encourage healthy eating habits. The four range, on the other hand, has not yet been developed for a variety of products that are sold separately. In order to improve the quality of the four categories of fruits and vegetables, there is a growing degree of interest in the exploitation of nonthermal cultivation techniques. Among the most important examples, it has been demonstrated that high-pressure processing and pulsed electric field processing play a role in the inactivation of particular enzymes and microorganisms in plant-based products without causing temperature increases or unwelcome changes in the sensory and nutritional aspects of the product. This is one of the most significant examples. On the other hand, it has been discovered that the outcomes are usually diverse depending on the kind of substrate, enzymes, or microorganisms. As a consequence of this, it is necessary to do additional research on these outcomes. According to Sharma, Perera, and others (2024), putting into practice these recently established approaches that are associated with cooling and modified environment packaging would be an attractive method for doing research.

References

1. Bhokarika, S. and K. Athmaselvi (2024). Functional Aspects of Plant-Based Food Products. Plant-Based Bioactive Compounds and Food Ingredients, Apple Academic Press: 61-72.
2. Chao, H., et al. (2024). "Effects of cold plasma treatment on reactive oxygen metabolism and storage quality of Brassica chinensis." Innovative Food Science & Emerging Technologies: 103574.

3. Dharini, M., et al. (2024). Impact of Cold Plasma on Physical Surface Modifications of Foods and Food Products. *Advanced Research Methods in Food Processing Technologies*, Apple Academic Press: 77-95.
4. Kaur, N., et al. (2024). "Aloe vera/Chitosan-Based Edible Film with Enhanced Antioxidant, Antimicrobial, Thermal, and Barrier Properties for Sustainable Food Preservation." *Polymers* 16(2): 242.
5. Mahmood, N., et al. (2024). "Application of emerging thermal and nonthermal technologies for improving textural properties of food grains: A critical review." *Comprehensive Reviews in Food Science and Food Safety* 23(1): 1-22.
6. Mahmud, N., et al. (2024). "Exploring functional plant-based seafood: Ingredients and health implications." *Trends in Food Science & Technology*: 104346.
7. Sandupama, P. and J. Wansapala (2024). "Development of micronutrients and bioactive compounds rich malted drink with selected plant-based ingredients." *Food Chemistry Advances* 4: 100575.
8. Sharma, S. et al. (2024). Natural antimicrobials from fruits and plant extract for food packaging and preservation. *Food Packaging and Preservation*, Elsevier: pp. 133–152.
9. Suri, K., et al. (2024). Thermal Modification of Plant-Based Proteins. *Novel Plant Protein Processing*, CRC Press: 95-115.
10. Bhokarika, S. and K. Athmaselvi (2024). Functional Aspects of Plant-Based Food Products. *Plant-Based Bioactive Compounds and Food Ingredients*, Apple Academic Press: 61-72.
11. Chao, H., et al. (2024). "Effects of cold plasma treatment on reactive oxygen metabolism and storage quality of *Brassica chinensis*." *Innovative Food Science & Emerging Technologies*: 103574.
12. Dharini, M., et al. (2024). Impact of Cold Plasma on Physical Surface Modifications of Foods and Food Products. *Advanced Research Methods in Food Processing Technologies*, Apple Academic Press: 77-95.
13. Kaur, N., et al. (2024). "Aloe vera/Chitosan-Based Edible Film with Enhanced Antioxidant, Antimicrobial, Thermal, and Barrier Properties for Sustainable Food Preservation." *Polymers* 16(2): 242.
14. Mahmood, N., et al. (2024). "Application of emerging thermal and nonthermal technologies for improving textural properties of food grains: A critical review." *Comprehensive Reviews in Food Science and Food Safety* 23(1): 1-22.
15. Mahmud, N., et al. (2024). "Exploring functional plant-based seafood: Ingredients and health implications." *Trends in Food Science & Technology*: 104346.
16. Sandupama, P. and J. Wansapala (2024). "Development of micronutrients and bioactive compounds rich malted drink with selected plant-based ingredients." *Food Chemistry Advances* 4: 100575.
17. Sharma, S. et al. (2024). Natural antimicrobials from fruits and plant extract for food packaging and preservation. *Food Packaging and Preservation*, Elsevier: pp. 133–152.
18. Suri, K., et al. (2024). Thermal Modification of Plant-Based Proteins. *Novel Plant Protein Processing*, CRC Press: 95-115.