Recent advancement in minimal processing of fruits and vegetables: A Review

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Abstract. Minimal processing is the fastest growing industry. The consumption of minimally processed foods has increased worldwide due to changing consumer attitudes towards fresh, healthy and convenient foods. In today's busy world, MPFV is an ideal food because it does not require additional requirements and provides a variety of minerals and vitamins necessary for human health. These new market trends have increased the need for the industry to explore new ideas to increase shelf life of the produce. The application of oil based nanoemulsions to minimally processed fruits and vegetables, used as cleaning or disinfecting agents, or added to food coatings, has been shown to significantly improve the microbiological quality and safety of minimally processed f&v. The antibacterial properties of essential oils reduce microbial activity, keeping the food fresh without compromising its quality. Other technologies, such as MAP on small-scale processors, can also play an important role. There are several strategies that can be implemented with the goal of reducing the rate of deterioration of fresh cut crops. The several new emerging technologies, are intelligent packaging, sensors, films, and modified atmosphere.

Keywords: Essential oil, MAP, Nanoemulsion, Intelligent packaging

1. Introduction

In recent years, minimal processing of fruits and vegetables have attracted a lot of attention from consumers due to the desire for good and healthy food. As there are several factors can cause an effect on the shelf life of minimally processed products, it’s important to use the methods that preserve and maintain the freshness, quality and nutritional value. The decrease in quality in fruits and vegetables is mainly due to tissue aging due to the initiation and progression of respiration and maturation (in climacteric f&v) and the depletion of energy reserves in climacteric and non-climacteric crops [2]. The main problem is that limited processing of fruits and vegetables increases metabolism, accelerates deterioration, biochemical changes and of the product. Fruits and vegetables and ensure the health of consumers. It’s useful, healthy and convenient product that saves time and effort while also providing several health benefits have intensified the market for minimally processed fruits and vegetables (MPFV) [1]. increases susceptibility to microbial contamination. Preparation activities of the unit, such as cutting, slicing, etc., cause in high respiration rate and become more susceptible to microorganisms, causing browning and other alterations more quickly [3] There has been a growing demand for natural compounds to develop new food remedies for pathogenic and spoilage microorganisms. Essential oils (Eos) are known for it’s natural antimicrobial compounds used as effective preservative systems in the food industry [4]. Advances in minimal processing product packaging are also being explored, including active MAP and smart packaging, edible coatings. Defining the control environment related to treatment, time and the correct dose/intensity is one of the biggest challenges when using physiological methods. Therefore, these aspects, as well as the safety and economic feasibility of each method, must be carefully evaluated [3].

1.1 Minimal processing

Minimal processing (MP) of fruits and vegetables is a blooming industry and have been growing a lot over the past years. The fresh cut produce industry is experiencing double-digit growth rates in response to growing consumer demand, particularly in developing countries [5]. These modern trends drive the market for minimally processed fruits and vegetables (MPFV) by promoting and increasing the demand for easy, useful, convenient food product that provides health benefits while also saves time and money [1]. MPFV offers high quality standards and a very fresh product with lots of vitamins, minerals, fibre and antioxidants. The main challenges
face by the minimally processed fresh cut fruits and vegetables: First, fresh products are delivered in simple conditions without compromising and losing nutritional value. The second is to improve the quality and increase the shelf life for a long time to increase the distribution capacity according to the customer’s needs [10,11]. By applying food coatings to fruits and vegetables, fresh and minimally processed foods are preserved for longer periods of time and protected from environmental damage. Processed or packaged fruits and vegetables The demand for an easy, convenient food products that not only save the time and money, but also provide the health benefits [1]. The interest in a new area of food preservation: minimally processed products. Other terms used to refer includes processed products, fresh products, Products that are prepared minimally processed are necessary to the food industry, such as restaurants and food catering companies, because they offer many different advantages over conventional products in terms of simplicity, cost, performance and hygiene [6]. foods are gaining momentum in the market due to the widespread belief that they can help meet today's essential nutrient requirements. Increase consumption of less processed and perishable foods, including vegetables and fruits, to reduce the risk of heart disease and cancer [7]. The primary concern is that inadequate handling of fruits and vegetables promotes metabolism, accelerates deterioration, triggers biological changes, and increases the likelihood of microbial contamination [8]. Generally When fruits and vegetables are cut, the process of processing or packaging causes a physical stress on the raw tissue which in turn reduces its quality and thus decreases it's shelf life. [9]. experience physical stress that reduces their quality and shelf life due to processing, resulting in reduced raw tissue. This direction was driven by the need to process high-quality, low-cost food. storage technology. It controls oxygen, carbon dioxide and moisture exchange, flavour and Odor compounds in food systems, edible coatings have demonstrated their ability to improve food quality and extend the shelf life of fresh [12]. Food packaging is the final step in the processing of fresh produce to protect the product and ensure safe distribution to consumers. Through packaging and cold chain management, it helps extend the shelf life and maintain the quality of fresh products [13].

1.2 Advances in minimal processing

Recent advancements in life extension technologies, such as physical, chemical, and biological preservation methods, have been linked to the preservation and improvement of the quality and safety of the fresh cut fruits and vegetables. [14]. There are several ways to preserve fruits and vegetables, but since freshly cut fruits are eaten fresh, heating and freezing methods are not suitable as they compromise their quality, nutrition and physical chemistry. As a result, finding effective strategies to prevent microbial growth while maintaining the quality of fresh-cut produce is of great interest to the food industry [15,16]. There are Several different methods, such as modified atmosphere storage and controlled atmosphere storage, have been used to preserve products by reducing quality changes and the amount of quality losses while storage. edible food coatings on fresh fruits and vegetables can be an effective way by controlling and adjusting the air inside individual fruits and vegetables, reducing changes in quality and quantity [17]. The concept of edible food coating for minimally processed products can be a barrier controlling the transfer of moisture, oxygen, carbon dioxide, aroma and flavor compounds to extend the shelf life and preserve the adverse effects of the external environment. Edible coating have the potential to improve the quality of minimally processed fresh-cut fruits and vegetable by extending shelf life and quality. edible coatings can include active ingredients such as antibacterial, antioxidants and nutrients, thereby improving product quality and safety [12]. The development of new processing technologies to preserve the fresh cut products must be able to overcome various barriers to the successful commercial distribution of such products. Plant essential oils have been a great way to improve the microbial activity of the minimally processed fruits and vegetable [18]. Essential oil based nanoemulsion has also been used in minimally processed food system to improve the microbial quality of the minimally processed fruits and vegetables. EO nanoemulsion is used by washing or soaking the solution on the food surface or by incorporating it a biopolymer edible coating [19]. the nanometric size and better distribution of nanoemulsions improve their bioactivity and reduce their impact on the sensory properties of foods. The growth of osmotically sensitive microorganisms such as yeasts, lactic acid bacteria (LAB) and molds can cause the spoilage in minimally processed products [20, 21].

![Fig.1: Minimal processing of capsicum (a) fresh capsicum (b) washed capiscum (c) fresh-cut capsicum (d) packed capsicum.](image-url)

1.3 Essential oil based nanoemulsion

EO acts as a defense agent, insecticide and growth inhibitor against a variety of plant pests. some of the most common EOs like Eucalyptus, Holy basil,
lemon and lemon grass have been extensively researched recently for antibiotics, insecticides, antioxidants, etc because EOs are highly volatile in nature, their optimal application is a difficult task and managing it efficiently without waste is hard. In addition, the lack of water and the low solubility in aqueous media make it difficult to add it directly to food. A good method for the efficient use of EO is its use in emulsion systems [22]. The most use emulsions are (O/W) and (W/O), although there are several emulsions and mixtures can be obtained. For example, combinations of plant essential oils (EOs) have been created to study the combined effects of their antioxidant and antibiotic properties. Specifically, clove and thyme EOs emulsified in a farsi gum coating were used in chilled rainbow trout fillets to increase shelf life [23]. Nanoemulsion droplets due to it’s size can be efficiently transported through outer membrane porin proteins, thanks to the size and visibility of the hydrophilic groups of the emulsifying molecules [24]. EOs are often carried in nanoemulsions to achieve greater stability than macroemulsions. Nanoemulsions of many plant based oils using nonionic surfactants are very safe, stable and biodegradable [25].

Fig.2: Functions of essential oil

1.3.1 EO nanoemulsion wash or soak on food surface

For minimally processed food systems, Essential oil based nanoemulsions can used in two different ways: 1) by using it for cleaning or dipping solution on food surfaces, and 2) by using OE nanoemulsions into polymeric food coatings or films [24]. Several recent studies have demonstrated the antibacterial potential of OE nanoemulsions in minimally processed food systems. For example, surface treatment of lettuce with 0.05% oregano oil nanoemulsion reduced L. monocytogenes, E coli O157:H7. [26]. Here, the authors saw no difference in results depending on the method of application, i.e. spraying or dipping [27]. Dipping is one of the main methods used for product coating due to its simple equipment-specific consistency and film. [28].

<table>
<thead>
<tr>
<th>Fruits/veg</th>
<th>Nanoemulsion</th>
<th>Impact</th>
<th>Refer-ence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Okra (Abelmoschus esculentus)</td>
<td>Basil essential oil</td>
<td>Increase the anti-microbial properties, preserve texture and colour</td>
<td>[28]</td>
</tr>
<tr>
<td>cherry tomatoes (Lycopersicum annum)</td>
<td>Oregano essential oil</td>
<td>Reduce the growth of bacteria, yeast and molds on the surface</td>
<td>[29]</td>
</tr>
<tr>
<td>Bell pepper (Capsicum annum)</td>
<td>Tea tree essential oil</td>
<td>Enhance the overall texture, extend the shelf life</td>
<td>[30]</td>
</tr>
<tr>
<td>Strawberry (Fragaria x Ananassa)</td>
<td>Cinnamon essential oil</td>
<td>Reduce the presence of Salmonella enterica.</td>
<td>[31]</td>
</tr>
<tr>
<td>Plum (Prunus domestica)</td>
<td>Lemongrass essential oil</td>
<td>Increase the antimicrobial activity and improve the homogeneity and stability of the emulsion.</td>
<td>[32]</td>
</tr>
<tr>
<td>Fresh-cut apples (Malus domestica)</td>
<td>Lemongrass essential oil</td>
<td>Antimicrobial, increase the shelf-life</td>
<td>[33]</td>
</tr>
<tr>
<td>Arugula leaf (Eruca sativa)</td>
<td>Lemon, oregano or clove oil</td>
<td>Reduce the microbial activity</td>
<td>[34]</td>
</tr>
<tr>
<td>Fresh-cut pineapples (Ananas comosus)</td>
<td>Citral</td>
<td>Improve the dispersion of active compound and increase the antimicrobial activity.</td>
<td>[35]</td>
</tr>
<tr>
<td>Grape berry (Vitis labruscana bailey)</td>
<td>Lemongrass essential oil</td>
<td>Reduce microbial activity</td>
<td>[36]</td>
</tr>
<tr>
<td>Green beans (Phaseolus vulgaris)</td>
<td>Lemon essential oil</td>
<td>Reduce the microbial and fungus growth</td>
<td>[37]</td>
</tr>
</tbody>
</table>

1.3.2 EO nanoemulsions coating onto fruits and vegetable surfaces
Edible coatings have been known and used for preserving the quality and shelf-life of food for centuries by forming a physical barrier that protects the food from the outside environment and by controlling the problem of moisture loss, gas barrier and physical damages [38,39]. The main EO components are those that play an important role in antibacterial activity[40]. Edible coatings extend shelf life of fruits and vegetables and prevent post-harvest losses by reducing respiration and moisture. Terpenes and ketones the best and most reliable plant essential oils are used when delivery systems are inadequate and are protected against dependence on other food particles. To reduce the impact in sensory attributes [41]. However, the direct use of EO as a coating agent in fruit and vegetable preservation is difficult due to its low water solubility, low viscosity, low stability, and polydisperse nature. Therefore, emulsification technology is used to improve the properties of EO [42].

1.4 Packaging

Packaging helps maintain the freshness and quality of food until it is consumed. While also providing safety and maintaining the organoleptic characteristics of food, it is possible to add active compounds and smart technologies to packaging that can provide information to consumers about the quality and authenticity of food. New types of packaging provide better oxygen, CO2 and water resistance properties, thereby increasing the shelf life of products [43] Examples of aging packaging used in MPFV are modified air packaging (MAP), air storage (CAS), active packaging, vacuum packaging, smart packaging, food films (EF) and coatings (EC) [44].

1.5 Modified atmosphere packaging

MAP is a technology that has been widely used in postharvest to maintain the quality of minimally processed food products and also to increase the shelf life under the best and ideal storage conditions [45]. One of the main focus in modified atmosphere in the packaging is to promote an environment of low oxygen levels and high Carbon dioxide levels, thereby reducing respiration, oxidative stress, aging of tissue and ethylene production. [46]. MAP are used for different types of minimally processed products and the specific mix of pack air depends in each case on the type of product, the product and the storage temperature [47]. When the permeability (to O2 and CO2) of the packaging film is adjusted to product respiration, an Equilibrium Modified Atmosphere (EMA) is established in the packaging and the shelf life of the product is increased [48,49].

**Table 2: Intelligent packaging and technologies for processed food products**

<table>
<thead>
<tr>
<th>Technologies</th>
<th>Mechanism</th>
<th>Uses</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAP</td>
<td>Control the O2 and CO2 levels.</td>
<td>Improve the moisture retention and preserve quality</td>
<td></td>
</tr>
<tr>
<td>Time temp indicator</td>
<td>Monitor cold chain logistics and food safety and quality</td>
<td>Indicated the quality for perishable foods help in storage and transportation</td>
<td></td>
</tr>
<tr>
<td>Freshness indicator</td>
<td>Monitor food freshness without damaging food and packaging</td>
<td>Helps indicate the food freshness, safety assessment and quality of perishable food</td>
<td></td>
</tr>
<tr>
<td>Gas indicator</td>
<td>Monitor the gases composition within the food packaging</td>
<td>Helps monitor the undesirable color change, improper sealing and detect any leakage of liquids of the packaging</td>
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</tr>
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</table>

1.6 Intelligent packaging of Fresh and Minimally Processed Product

Intelligent packaging, also known as active or smart packaging. The food packaging are incorporated with new technologies like sensors that monitor the quality, safety, temperature, and condition of foods along the supply chain [53,54]. Intelligent helps in smooth flow of the food supply chain [55]. Intelligent packaging provides both food safety and quality by providing the information [56], and could be a point of difference utilized in innovative packaging designs. [57] intelligent packaging is an effective tool for tracking products, monitoring their status, simplifying data entry and communication, and supporting rapid response and accurate decision-making. These properties are essential to any food safety or biosecurity strategy [58]. It is one of the best and effective tools for detecting any kind of adulterations in the food specially during supply chains [59]. Various indicators and sensors such as the growth of TTI, gas indicator, presence of microbes and the product’s authenticity, and the
integrity of the package are used in intelligent packaging [52].

1.6.1 Time-temperature indicator
The temperature time tag (TTI) is a small self-fixative label that is attached to shipping containers or in individual consumer packages. These labels provide an indication and information of the temperature history during distribution and storage, and are particularly useful for warning of temperature deterioration in frozen or deep-frozen foods. It is also used as a "new indicator" to estimate the remaining useful life of perishable products. The response of these labels varies with temperature, such as an increase in colour intensity and colour distribution in the right direction. There are three basic types of TTI that are commercially available: critical temperature signals, partial recording signals, and full recording signals [60].

1.6.2 Gas indicators:
Gas indicator helps with monitor the changes in the gases composition in the packaging. The use of gas indicators, such as packaging labels or packaging films, can provide a means to monitor food quality and safety by monitoring changes in gas composition [61]. O2 and CO2 indicator is the most common gas indicator use in packaging, the indicator is design to detect the changes in gases and show colour [62].

1.6.3 Freshness indicator:
Freshness indicators is a device that detect and senses the changes occurring inside a package (PH, gas composition, etc.). Then the change later get transformed into a colour response which can be correlated with the freshness of food products [63]. Unlike temperature indicators, the freshness indicators are direct measures of food quality. The main idea is that the growth of microorganisms leads to an irreversible change, such as a change in pH (which result in colour change in the packaging), which is a direct indicator of the quality of the food contained in the package. [64].

2. Challenges in minimally processed fresh cut fruits and vegetable
The main challenge in the fresh cut minimally processed fruits and vegetables that they more susceptible to microbial spoilage the living cut tissues increased metabolism, resulting in faster spoilage and biochemical changes [8]. The consumer's demand for simplicity, freshness, safety, and natural products with less additives and preservatives to preserve food quality is offset by the new technologies used in MPFV. To meet this criteria of the consumers, different alternative methods and technologies must be environmentally friendly and cost-free. Although important, these factors alone do not guarantee a wide success in the international market. Because the success of new technologies for Minimal processing of fruits and vegetable depends mainly on consumer acceptance. [65].

3. Future prospects
Developing countries like India are leading innovation in the minimal process fresh cut produce industry. Government regulations and large retailers require higher sanitary design standards for processing plants and packaged foods. A future perspective in the field of minimally processed fruits and vegetables is the incorporation of nanoemulsion and intelligent packaging. These developments have the potential to extend shelf life by inhibiting microbial growth and improving antioxidant properties. Advances in sensor technology enable real-time monitoring of quality parameters such as freshness and microbial contamination, promising to improve safety and consumer satisfaction throughout the supply chain.

4. Conclusion
In conclusion, recent advances in minimal processing of fruits and vegetables have shown promising strategies to improve their quality and shelf life. The use of edible nanoemulsion coatings of essential oils has emerged as a viable solution that provides antimicrobial properties and long-lasting freshness. In addition, an important success is the integration of intelligent packaging systems equipped with sensors and indicators that enable real-time monitoring of product conditions and ensure optimal storage environments. These innovative approaches not only extend the shelf life of minimally processed produce but also contribute to reducing food waste and enhancing consumer satisfaction.

Declaration of competing interest
No conflict of interest

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