MANGO BOARD

LITERATURE REVIEW

STRATEGIES FOR FRESH-CUT MANGO PRESERVATION:

INSIGHTS FOR THE MANGO INDUSTRY

FRANCINE LORENA CUQUEL
VOLNEI PAULETTI

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STRATEGIES FOR FRESH-CUT MANGO PRESERVATION:

insights for the mango industry

Francine Lorena Cuquel [(1)] and Volnei Pauletti [(2)]

[(1)] Crop Science Department, Universidade Federal do Paraná, Brazil
[(2)] Soil Science Department, Universidade Federal do Paraná, Brazil

Executive Summary

In support of fruit processors, this literature review recapped recent technologies that can maintain the quality and extend the shelf-life of fresh-cut mango (FCM). This demand is given by the largely variable and rather modest visual and sensory conditions for US consumers. The shelf-life of FCM lasts around 10 days, according to the mango cultivar, pre-harvest agronomic practices, harvest maturity and postharvest management. Depending on the cultivar, the mango firmness for harvest to product FCM is between 25 (5.62 lbf) and 35 N (7.86 lbf). In unripe FCM, the desirable sensory properties cannot be fully exploited, while sensory evaluations with trained graders are very scarce. The ideal temperature range to prolong FCM shelf-life and reduce the risk of proliferation of microbial foodborne human pathogens is storage at 4 - 5 ^{o}C, not exceeding 8 ^{o}C. A general concern is to avoid chilling injury at temperatures below 10 °C (the degree of chilling sensitivity of mango stored at low temperature is cultivar-dependent). In the FCM industry, a balance between an acceptable shelf-life and appealing sensory properties must be found, to be able to offer a high-quality product that meets the expectations of all parties. Foodborne pathogens can survive or grow at the said low temperatures. Therefore, aside from refrigeration, manufacturing and packaging practices must also be optimized to effectively control foodborne pathogens in FCM. Supercooling by oscillating magnetic fields (OMF) has been used mainly to inhibit ice nucleation (crystal formation). By this technique, minimally processed mango fruits are frozen at a temperature of - 5^{O}C for up to 7 days without ice crystal formation within the cells. The enzymatic browning potential of FCM can vary significantly among mango cultivars. Calcium is a vital macronutrient that plays an important role in avoiding FCM browning. Edible coatings with products containing calcium, chitosan, citric acid, plasticizers, plant extracts, and nanocomposite materials are discussed. The main FCM foodborne microorganisms, e.g., *Salmonella* spp., *Bacillus spp., Micrococcus spp., Staphylococcus* spp., *Klebsiella* spp., *Pseudomonas* spp. and *Escherichia coli* and their control with sanitizers and natural additives were described. Ecofriendly technologies and non-thermal technologies have been a trend. Ultraviolet-C (UV-C), pulsed-light (PL), light-emitting diode (LED), cold-plasma (CP), high-intensity ultrasound (HIU), neutral electrolyzed water (NEW), acidic electrolyzed water (AEW), modified atmosphere (MA) and packaging were discussed with a view to increasing the shelf-life of FCM. We concluded that very few alternatives have been exploited to increase the quality and shelf-life of the product. In view of the lack of information related to the most recent findings for FCM, observed in this review, in the end we proposed some topics for future research that can be addressed to improve FCM quality and shelf life.

Keywords: *Mangifera indica*, minimally processed, browning, edible coating, sanitizer, microbiologic control, ultraviolet-C, pulsed light, cold plasma, high intensity ultrasound, electrolyzed water, modified atmosphere, packaging.

Contents

1. Introduction

The visual and sensory conditions of fresh-cut mango (FCM) offered to US consumers during a year-long cycle of imports from different countries are mostly variable, but rather modest. The use of optimum processing practices and proper packaging and handling after processing are also critical to obtain consumer satisfaction (Brecht et al., 2017). This literature review focused on the recent technologies that guarantee the quality and extend the shelf-life of FCM, to offer additional support for processors. A description will be given of the effects of low temperature storage, edible coatings, anti-browning substances, sanitizers, thermal and non-thermal disinfection, modified atmosphere and packaging.

2. Methods

The literature review was carried out from January 1 to July 31, in 2023. The systematic literature search strategies and article eligibility criteria are presented in this section.

2.1. Eligibility criteria

The following eligibility criteria were used to collect FCM-related literature:

- **Inclusion criteria**: the literature review included FCM together with the keywords: quality, shelf-life, storage, cultivars, ripening, chilling, microbiological control, sanitizer, edible coating, modified atmosphere and packaging, in peer-reviewed journals from 2013 to 2023 in English and, finally, the most important papers previously published and cited by the authors of the articles chosen based on the above criteria.
- **Literature review scope:** search in the most important Agricultural Science four Databases: Web of Science, Scopus, Science, Direct and Google Scholar with the inclusion criteria keywords (Table 1). Bibliometric methods as described by Donthu et al. (2021) showed that the frequency of terms related with “fresh-cut mango shelf-life” worldwide in decreasing order is mango - 6, quality - 4, fresh-cut - 3, mango fruit - 3, storage - 3, chitosan - 2, FCM - 2 and softening - 2.
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Table 1. Number of articles cited in the database sources on fresh-cut mango shelf-life and a second related keyword.

Databases	Number of articles
Web of Science	60
Scopus	64
Science Direct	18
Google Scholar	31

3. Worldwide importance of mango

Economically, mango (*Mangifera indica* L.) is one of the most important tropical fruits. Owing to its pleasant aroma, juicy texture and sweet taste, it is highly popular among consumers around the world and is known as "the king of tropical fruits" (Yi et al., 2022). Certain phytonutrients (carotenoids, flavonoids, dietary fibers and microelements) found in mango fruit possibly have health-promoting effects, such as scavenging free radicals, being digestive and maintaining the cellular electrolyte balance (Maldonado-Celis et al., 2019).

The world production of mango has doubled since 2000 (Perea-Moreno et al., 2018) and is expected to reach 65 million tons in 2028, with an annual growth rate of about 2.1% (Organisation des Nations Unites pour L'alimentation et L'agriculture, 2020; Taïbi et al., 2022).

More than 90% of the global production is destined for the respective local markets or neighboring countries (Organisation des Nations Unies pour L'alimentation et L'agriculture, 2020). International exports are estimated at a continuous 3.4% of the worldwide production until 2028 (Taïbi et al., 2022). As an imported commodity in Asian, European and North American markets, mango has increasingly gained in popularity.

Very little of the high world production of mango is being processed to increase fruit preservation (Link et al., 2018), thus, extending the shelf-life is still an important issue.

4. Rising importance of fresh-cut mango

Nowadays, the demand for fresh-cut products has increased in response to the quality demand and modern lifestyle of consumers (Chimvaree et al., 2020; Yi et al., 2022; Yildiz and Aadil, 2022). Tesco, one of the largest fresh-cut retailers in the global market, reported that the demand for healthy fruit snacks, such as mango "fingers", has increased by 400% between 2016 and 2017 (Tesco, 2017). Mango belongs to the fruits suited for minimal processing, a feature that meets the increased market demand of ready-to-eat fresh fruit products (Yousuf et al., 2018). Processed mango products are abundantly available in form of fruit salads, dried slices, frozen chunks and slices, canned slices, jams, traditional pickles and chutneys. This value-added product can be sold at a higher price (Ulloa et al., 2015) and indicates an alternative way to minimize post-harvest losses (Taïbi et al., 2022).

5. Fresh-cut mango quality

Postharvest processing of mango induces biochemical changes, increases fruit respiration rate, tissue softening, and the decompartmentalization of enzymes, intensifies antioxidant activity, raises polyphenolic contents and stimulates the development of undesirable color changes due to enzymatic browning. Freshly cut mango also provides a substrate for microbial growth, increasing the risk of developing pathogens. Therefore, the shelf-life of fresh-cut fruit is considerably shorter than that of whole fruit (Robles-Sanchez, 2013;

Ngamchuachit et al., 2015; Marín et al., 2020). Even after preservation treatments to extend shelf-life, FCM has a consumption adequacy period of only a few days (Salinas-Roca et al., 2017; Putnik et al., 2017; Chimvaree et al., 2020; Owino and Ambuko, 2021; Luciano et al., 2022; Yi et al., 2022).

Several studies suggested the importance of sensory evaluations with trained graders to determine the shelf-life of fresh-cuts products. However, sensory evaluation protocols can be time-consuming and expensive, and some authors do not think it is necessary to repeat FCM sensorial analysis for every FCM research (Salinas- Hernández et al., 2015).

According to Salinas-Hernández et al. (2015), studies have shown that sensorial properties may be correlated with physicochemical features, and they can be used as predictors of FCM shelf-life, since they attain almost the same level of reliability as sensory analysis by trained panelists or consumers. The above authors recorded high correlation coefficients between shelf-life inferred from consumer acceptability scores and physicochemical variables. The lightness (L*) of the product is clearly related with color and brightness, whereas firmness is related with texture. Total soluble solids (TSS) can be associated with sugars and organic acids and are therefore related with fruit flavor and sweetness. In addition, chroma and hue angle are related with color and color intensity.

However, Ngamchuachit et al. (2015) did not agree with Salinas-Hernández et al. (2015) but claimed that the physicochemical properties of FCM cannot always be used as predictors of the sensory quality. The former authors suggested that it is necessary to previously consider the firmness and color of the product of each cultivar (the coordinate that measures the colors between red/green (a*), the coordinate that measures the colors between yellow/blue (b*) and their relations (a*/b*)) to predict the visual and sensory quality of FCM 'Kent'. The L* value and instrumental firmness of FCM 'Tommy Atkins' proved useful as predictors for texture properties, i.e., melting, slipperiness, chewiness and firmness. Interestingly, SSC, titratable acidity (TA) and SSC/TA were rather poor predictors of sensory sweetness.

6. Factors affecting fresh-cut mango quality

Factors that are fundamental for FCM quality include the quality of the intact (uncut) mango, cultivar, pre-harvest agronomic practices, harvest maturity, postharvest handling procedures, processing and preparation methods, i.e., sharpness of cutting tools, size and surface area of the slices, washing and removal of surface moisture, storage, and processing temperature (Shende et al., 2020; Owino and Ambuko; 2021). In addition, FCM must be stored at no more than 5 ^{o}C, to prolong shelf-life and reduce the risk of potential proliferation of microbial food-borne human pathogens (Food and Drug Administration, 2017). Under these conditions, unripe FCM cannot fully develop desirable sensory properties, such as appearance, brightness, browning, odor, flavor, texture, color, acidity, and sweetness (Salinas-Hernández et al., 2015), which may negatively affect the repeat-purchase behavior of consumers. In this context, the FCM industry needs to reach a balance between acceptable shelf-life and appealing sensory features, to offer a high-quality product that meets the expectations of all parties involved. Processing riper fruit might be a way to achieve this goal, although this can simultaneously increase susceptibility to wounding during processing and reduce the shelf-life (Robles-Sanchez et al., 2013; Ngamchuachit et al., 2015; Brecht et al., 2017; Marín et al., 2020).

FCM the ideal storage temperature is 4 ^{o}C as, while 8 ^{o}C can also be an option to store it safely for 10 days (Luciano et al., 2022), but some foodborne pathogens can survive or grow under these temperatures. *Listeria monocytogenes* growth in FCM is a concern because of its ability to grow under cooling, with or without oxygen for weeks to months (Zhang et al., 2020). *Escherichia coli* and *Salmonella* spp can also survive during storage at 5 °C, while psychotropic *Listeria monocytogenes* can grow at 4 °C. Thus, together with refrigeration, good manufacturing and packing practices (Brecht et al., 2023) must be applied to effectively control foodborne pathogens on fresh-cut fruits without deterioration (Kim et al., 2017).

7. Mango cultivar performance

Key decisions for the success of FCM consist of the selection of a mango cultivar with excellent quality and processing potential at the optimal ripening stage for fresh-cut processing. The choice should be based on appearance and sensory and overall quality (Dea et al., 2013; Sellamuthu, 2013). A challenge is that mango cultivars can vary significantly in pulp texture, skin color, flavor, functional compounds, storage period and browning potential (Sellamuthu et al., 2013). Enzymatic activities vary according to the mango genotype (Romig, 1995). So, cultivars with reduced key enzyme activity and consequently less browning, softening, and volatile compounds, such as can be seen in the 'Totapuri', an Indian mango cultivar, are generally more desirable for minimal processing (Sharma and Rao, 2017).

Generally, fresh mango fruit shelf-life is limited to just a few days, which depends on the mango cultivar. 'Ataulfo' fruits stored at 5°C have a shelf-life of 21 days and 'Keitt' fruits of 9 days. On this basis, the latter is more indicated for FCM production (Bhatkar et al., 2022) because it helps to decrease the postharvest losses. In addition, 'Kent' is more desirable to product FCM due to its better sensory quality during storage compared with 'Tommy Atkins' (Ngamchuachit et al., 2015).

8. Ripening stage for harvest

The mango ripening stage at the time of cutting is an important factor that affects the FCM quality (Ngamchuachit et al., 2015) and is more reliable to predict FCM shelf-life than pulp color or soluble solids content (SSC) (Dea et al., 2013). Mango fruits are acidic, astringent and rich in ascorbic acid (vitamin C). During the ripening process, the level of vitamin C decreases and the levels of pro-vitamin A, vitamins B1, and B2, sucrose (the major sugar), fructose, and glucose increase (Montoya et al., 2019).

To slow down fresh-cut fruit deterioration, processors tend to cut mango on reception without pre-ripening to avoid overripe, soft, bruised and decayed fruit (Brecht et al., 2017). Mango fruits processed at an earlier ripening stage resulted in acid FCM and with poor aromatic properties, affecting the product quality (Leneveu-Jenvrin et al., 2021).

The ideal firmness level for the harvest of mango destined for FCM is based on the ease of handling, visual quality (primary purchase criterion), and quality maintenance during storage, and consumer acceptance. They all depend on the mango cultivar. For 'Kent' mango, fruit firmness is assumed to be best between 35 N (7.86 lbf) (Ngamchuachit et al., 2015) and 30 N (6.74 lbf) (Dea et al., 2013). However, for 'Tommy Atkins' the best fruit' firmness is 25 N (5.62) (Ngamchuachit et al., 2015). Fresh- cut mango (of several cultivars) provided by tropical fruit importers in the USA that had least browning, translucency, fermented off flavor, and the greatest cut edge sharpness occurred when firmness of the stored fruit was 35 N (Plotto et al., 2018).

9. Storage temperature

Fresh-cut fruits are highly perishable and must be stored under refrigeration after packaging to ensure safety and sensory quality (De Corato and Cancellara, 2019). Generally, storage and shipping last no longer than 10 days, but cut fruits can have an even shorter shelf-life if storage conditions are inappropriate (Amaro et al., 2018; Luciano et al., 2022).

The performance of FCM of four mango cultivars ('Kesar', 'Ladvo', 'Rajapuri' and 'Totapuri') varied widely during low temperature storage. In response to the storage condition at 5± 1°C and 95% RH, the quality properties represented by bioactive compounds (vitamin C, carotenoids, total phenolic content and antioxidant activity) and sensorial properties (visual perception, though taste, odor and firmness) improved considerably when compared to FCM stored at 10± 1°C and 87% RH. Moreover, the storage of these FCM cultivars at

5 °C ± 1°C showed lower water loss and microbial contamination (Sharma and Rao, 2017).

Low temperature storage is highly recommended for fresh-cut fruit as it can slow down ethylene sensitivity and metabolic activities reduce microbial growth and extend the shelf-life (Sharma et al., 2017). Restaurants and consumers usually store FCM together with other products between 4 and 8 ºC, which can cause chilling injury (CI) on the product, depending on the mango cultivar and time (Taïbi et al., 2022). But, in contrast when mango fruit is exposed to temperatures below 10 °C, chilling injuries (CI) occur because of malfunction or disruption of cellular wall and membrane functions that affects the transfer or flow of cellular fluids in and out of the cell, resulting in irregular metabolites (amino acids, sugars and mineral salts). The degree of chilling sensitivity of mango varieties under low temperature storage has been documented in a number of studies. Nevertheless, the response to cold storage of chunks prepared from various mango cultivars, mainly in terms of changes in nutritional quality as well as sensory properties, still needs be investigated (Sharma et al., 2017).

10. Oscillating magnetic field (OMF)

Supercooling by oscillating magnetic fields (OMF) has been used mainly to inhibit ice nucleation, i.e., a process of lowering the temperature of food material below its freezing point without allowing ice crystal formation. In a supercooled state, latent heat removal and the following phase transition do not occur. In this way, freezing damage during storage can be avoided. Supercooling preservation potentially extends the shelf-life of food without ice crystal formation. However, it is extremely difficult to create and maintain a supercooled state over an extended period because this metastable state is thermodynamically unstable (Stonehouse and Evans, 2015). The application of an external magnetic field (MF) has attracted considerable interest of the food freezing industries. It has been hypothesized that since MF can interact with water and induce reorientation and realignment of water molecules, these changes would inhibit or promote ice nucleation during the freezing process (Kang et al., 2021).

An OMF at a field strength of 50 mT applied for the supercooling preservation of FCM chunks, which preserved in a supercooled state at -5◦C for up to 7 days. The quality assessment, which assessed weight loss and firmness, indicated that supercooling preservation potentially extended the shelf- life of fresh-cut mango without losing the original quality (Kang et al., 2021).

11. Enzymatic browning

Peeling and cutting operations involved in processing FCM eliminate the protective pericarp, which greatly disrupts the integrity of product tissues, leading to wounding stress, increased water loss, flavor loss, tissue softening and enzymatic pulp browning (Charles, 2013b; Montoya et al., 2019; Khedr, 2022; Yi et al., 2022).

Enzymatic browning indicates the water-soaked appearance of fruit tissues, known as one of major concerns, related to FCM quality (Supapvanich and Boonyaritthongchai, 2016; Chimvaree et al., 2020). It results from undesirable physio-biochemical reactions, such as increases in respiration intensity and ethylene production, activation of oxidases and burst of reactive oxygen species (ROS) (Yi et al., 2022). This occurs when the enzyme polyphenol oxidase (PPO) is released into the cytosol and the reactions are triggered. The reaction occurs between O_2 and PPO, where monophenol is hydroxylated to o-diphenol and diphenol could be oxidized to o-quinones, which undergoes polymerization resulting in black-brownish pigments (Yildiz et al., 2020).

The enzymatic browning potential of FCM can vary significantly among mango cultivars (Ngamchuachit et al., 2015; Sharma and Rao, 2017). ‘Tommy Atkins’ responded to antioxidant solutions much more readily than ‘Kent’ with reduced slice browning. ‘Tommy Atkins’ slices treated with an antioxidant solution had a shelf-life of 10 days and uncoated slices less than 7 days, whereas 'Kent' chunks, treated with antioxidant solution, were marketable for 11 days (Marín et al., 2020). Although browning was not intensified in low-maturity mango fruits, this feature defined the low quality of the final product (Leneveu-Jenvrin et al., 2021).

Calcium is a vital macronutrient that plays an important role to avoid browning, by maintaining cell wall firmness and integrity; in addition, it is responsible for fruit quality (Manganaris et al., 2005). In principle, there are two ways to increase the calcium concentration in fruits. First, by increasing calcium import through the xylem. This way can be effective in the early fruit growth phases. The second way consists of foliar application of one or more calcium salts (usually calcium chloride, calcium nitrate, or calcium hydroxide) (Winkler et al., 2020; Khedr, 2022).

Pre-harvest foliar application of 2% calcium lactate on 'Keitt' mango trees in combination with post-harvest treatments of FCM with 2% ascorbic acid (AsA), cold stored at 4°C for 12 days, was the most effective treatment, without affecting quality or taste, compared with untreated FCM (Khedr, 2022).

Calcium ascorbate (CaAs) has been found to be the most effective anti-browning agent and can be marketed as a minimal chemical input. Its application increases the antioxidant status and extends shelf-life of several fruits. Several studies have focused on combined techniques with better antifungal efficiency than the chemical alternatives. The combination of hot water (HT) and calcium treatments has been used to control postharvest diseases and has sucessfully maintained the postharvest fruit quality (Boonyaritthongchai and Keawmanee, 2020).

Hot water alone or in combination with other agents, e.g. calcium salts, has been used to prevent browning reactions and maintain the texture of various vegetables and fruits. The combination of HT (50ºC for 30 min) treatments of the whole mango, followed by of FCM immersion in 2% CaAs dip and storage at 4ºC for 6 days, resulted in browning reduction and high sensorial acceptance

(Bonyaritthongchai and Keawmanee, 2020). Steam treatment (ST) of FCM at 60°C for 3 min reduced polyphenol oxidase activity by 72% and decreased browning but caused a loss of brightness (Leneveu-Jenvrin et al., 2021).

To investigate the effect of anti-browning agents on fresh-cut mango, the inhibitory activity of four solutions (ascorbic acid, citric acid, L-cysteine and glutathione) were tested (Marín et al., 2020). Results indicated that the degree of changes in pulp color of FCM was related to the concentration of the different anti-browning agents. Among the tested compounds, L-cysteine and glutathione were most effective to inhibit browning. Moreover, these agents reduced the respiration rate, inducing a decrease in metabolic activities and suppressing the enzyme activities of PPO and POD and tissue metabolism. This slowed down the quality losses in terms of color of FCM pulp, while citric acid significantly inhibited microbial growth (Techavuthiporn and Boonyaritthonghai, 2016). Citric acid was found to be the most effective antibrowning agent (Marín et al., 2020).

The use of synthetic chemicals to treat fresh-cut products has become unpopular due to growing concerns about food safety. For this reason, research is being conducted to develop alternative methods to control browning in minimally processed products. For example, studies have demonstrated the browning inhibiting and quality-maintaining potential of natural agents such as aloe vera (Alberio et al., 2015), whey protein (Yi and Ding, 2014), and rice bran extracts (Sukhonthara et al., 2016). However, no research on the efficacy of natural agents in preventing browning of FCM is available (Chimvaree et al., 2020).

A potential for visual appearance maintenance and browning and discoloration inhibition was observed in FCM ‘Nam Dok Mai’, a famous commercial Thailandese cultivar with high susceptibility to tissue browning, by dipping the cut pieces in 25% honey for 2 min (Supapvanich and Boonyaritthongchai, 2016). Another way to control browning of this cultivar is by dipping the mango pieces in 50% pineapple juice extracted from the pineapple core, then exposing them to air drying, packaging in a plastic box and storage at 4°C for 6 days. Sensory evaluation proved the efficacy of pineapple juice dipping by the maintenance of the overall quality (Boonyaritthongchai et al., 2018).

12. Edible coating

The use of edible coatings for an extended shelf-life and improved quality of fresh-cut fruit is an extensively studied strategy (Ghidelli and Pérez-Gago, 2018; Yousuf et al., 2018). These coatings preserve the FCM quality by reducing weight loss, delaying the increase in SSC, maintaining pH, total acidity and reducing microbial growth. Edible coatings affect oxygen partial pressure and metabolism of fresh food and favor volatile component retention. They control moisture migration between the food product and the environment, protecting it from deterioration, improving the textural quality and decreasing the risk of pathogen growth (Afifah et al., 2019). The coating materials should not confer taste and should improve the keeping quality of the product (Salinas-Roca et al., 2018a).

Some of the most notable benefits of edible coating are the delay of pulp browning and tissue softening. The incorporation of antibrowning and/or firming agents such as calcium ascorbate, citric acid and N-acetyl-L-cysteine into edible coatings is known as an effective tool to enhance their efficacy and is frequently used in the fresh-cut industry. Polysaccharide-based edible coatings have been widely reported as good matrices to incorporate compounds with antibrowning properties in fresh-cut mango and other fruit (Robles-Sánchez et al., 2013; Marín et al., 2020; Bhatkar et al., 2022).

Among the coating agents, chitosan (Pengnet et al., 2014; Gurjar et al., 2018; Salinas-Roca et al., 2018a) and citric acid (Marín et al., 2020) are considered the most effective antibrowning agents, which additionally reduced weight loss, prevented biochemical changes and inhibited microbial growth on FCM. A sensory evaluation of FCM with and without chitosan coating confirmed sensorial similarity of the coated and uncoated fresh-cut pieces (Afifah et al., 2019).

Plant extracts have the potential to be used as food additives; however, their use is subdued by the undesirable changes they cause in the sensory properties of food (Bernal-Mercado, 2018). However, the results of ethanolic seed extract from mango seeds as coating material of FCM have been promising, not only as antimicrobial agent, but also regarding the increase in phenolic compounds (Vega-Vega et al., 2013; Bernal-Mercado, 2018).

The protein sericin, a natural macromolecular, water-soluble protein, is derived from silkworm. It has been included in the “Generally Recognized as Safe-GRAS” list (Food and Drug Administration, 2001) and can be used as an edible coating for fresh-cut products because it can inhibit the activity of enzyme polyphenol oxidase (PPO). As a coating to FCM, it reduces water loss, which contributes to maintaining the texture (Chimvaree et al., 2019).

Strong interactions can occur between the plasticizers added to the polymer matrix, to improve certain functional properties of the film. Major plasticizers have been used are polyols, such as glycerol, polyethylene glycol, and sorbitol, besides, disaccharides, such as sucrose, and monosaccharides (e.g., fructose, glucose, and mannose) (Zhang and Han, 2016). Type and amount of plasticizers affect properties of the coating (Kokoszka and Lenart, 2007). Hence, their polymer types and optimum concentration of plasticizers should be determined for the success of its use in a variety of condition. Edible films containing two plasticizers had a greater thickness and higher water vapor transmission rate and solubility than film with a single plasticizer. The presence of plasticizers in the coating formulation confers different physical and chemical properties to the film; thus, appropriate selection is required (Afifah et al., 2019).

Composite coating of sesame protein isolate (5%) and mango puree (30%) on fresh mango pieces was less affected by drip loss and improved color and firmness preservation (Sharma et al., 2019).

Nanocomposites are materials with at least one component with nanometric size (1 - 100 nanometers), which consists of natural polymers as matrix with nanoparticles as filler. Nanocomposite edible coating improves the stability of FCM storage quality and postharvest life. The incorporation of nanoparticles into biopolymers can enhance the characteristics and functional properties including barrier ability, morphology and mechanical strength. Nanocomposite edible coating of fresh-cut cassava with zinc oxide nanoparticles and stearic acid successfully conferred a shelf-life of 12 days at 8°C (Yuliani et al., 2018). Alginate-Chitosan nano-multilayer edible coating extends the shelf-life of FCM up to 8 days (Souza et al., 2015).

13. Microbiological aspects of FCM

Fresh-cut food products remain the leading cause of foodborne illness outbreaks (Callejón et al., 2015). Many microorganisms are found in improperly processed fresh-cut products, in particular *Salmonella* spp*., Bacillus spp., Micrococcus spp., Staphylococcus* spp*., Klebsiella* spp*., Pseudomonas* spp*.* and *Escherichia coli* (Finger et al., 2019), which contribute to high morbidity rates in several countries (Lopes et al., 2021). Among these, bacteria are the greatest cause of foodborne diseases (Draeger et al., 2019).

The surface of mango fruit is covered by a wide variety of microorganisms, which can be found in processed products. (Bokulich et al., 2015; Machado-Moreira et al., 2019; Taïbi et al., 2022). The available water content of cut fruit (about 80%) (Ntuli et al., 2017), together with the readily available sugars, favor microbial growth and compromise both food safety and quality (Taïbi et al., 2022).

Salmonellosis is an important cause of foodborne outbreaks in the United States and Canada due to fresh produce consumption (CDC, 2012). Additionally, other members of the Enterobacteriaceae family may occur naturally on plant material, namely the genera *Pantoea, Klebsiella, Pectobacterium* (Leff and Fierer, 2013) and Cronobacter (Garbowska et al., 2015; Vojkovska et al., 2016;

Santo et al., 2018). Steam treatment (ST) at 60°C for 3 min maintained the microbial population below 2.5 log CFU/g (colony-forming units per gram) after 10 days of storage (Leneveu-Jenvrin et al., 2021).

For all mangoes entering the United States, the U.S. Department of Agriculture-Animal and Plant Health Inspection Service mandates a quarantine heat treatment consisting of exposure to 46 °C water for 65–110 min (depending on cultivar and fruit size) (USDA-APHIS, 2002). This procedure is used by producers/ packers to eliminate fly larvae. In all steps, incorrect human handling is a major source of contamination (Graça et al., 2015, 2017; Santo et al., 2018). In any case, a disinfection phase is mandatory in the flowchart of fresh- cut fruit production, and washing with sodium hypochlorite solutions is the most applied method (Santo et al., 2018). Mango can be contaminated with *Salmonella enterica* if the water used for washing during the heat treatment is contaminated. High temperatures of washing/rinsing water may contribute to the internalization of pathogens that may be present in the water (Penteado, 2017). Thus, the microbiological quality of water used in the post-harvest phases is essential.

Cronobacter sakazakii, an important pathogen for neonates and immunocompromised adults, has been isolated from various plant food sources, although it has not been associated to outbreaks resulting from the fruit consumption, including mango (Penteado et al., 2014; Ma et al., 2016). Serovars of *Salmonella enterica* tested on ‘Palmer’ were not able to grow at 28 ^{o}C and 4 ^{o}C (Ma et al., 2016). However, *S. enterica* serotype *enteritidis* was able to grow in pasteurized pulp of ‘Palmer’ mango, at 25 ^{o}C, after an adaptation phase of 19 days (Penteado et al., 2014).

Despite the recommendation for low-temperature storage, fresh-cut fruit is often exposed to temperature changes during processing and distribution, caused by the opening and closing of refrigerator doors in retail outlets and supermarkets or of domestic fridges (Luciano et al., 2022). This exposure can facilitate pathogen growth and proliferation and compromise food safety (Huang et al., 2019).

14. Sanitizer compounds

The most used chlorinated sanitizers for minimally processed products with antimicrobial activity are sodium hypochlorite (NaClO) and calcium hypochlorite ($CaCl_2O_2$). These products are relatively inexpensive and easy to apply (Lopes et al., 2021). The recommended dose of chlorine products for FCM is 50 - 200 ppm, at a pH of 6.0–7.5 and a contact time of 2–5 min (Suriati et al., 2021). However, in the presence of organic material, as is the case when fresh-cut products are sanitized, hypochlorite reacts with the organic matter and produces carcinogenic compounds such as chloroform ($CHCl_3$), trihalomethanes and teratogenic haloacetic acids (Teng et al., 2018). At alkaline pH, chlorine can react with nitrogenous bases, producing chloramines (NH_2Cl), which are also carcinogenic (Wastensson and Eriksson, 2020). For these reasons, the Maximum Residue Limit (MRL) of sodium hypochlorite has been set at 0.01 mg Kg^{-1} in the United States (FDA, 2001). In addition, the high reactivity of chlorine with organic matter, in the presence of oxygen, reduces the free chlorine content in water. Therefore, the sanitizing solution must be exchanged after 2 - 3 uses, when the free chlorine concentration sinks below 50 μL L^{-1} (Teng et al., 2018).

Ozone (O_3) kills microorganisms by oxidizing vital cell components. However, if inhaled it is toxic, and causes symptoms such as breathing difficulties, irregular heartbeat and drop in blood pressure above 3 mg L^{-1}. Inhalation of more than 20 mg L^{-1} for 1 h (or 50 mg L^{-1} for 30 min) may be fatal. It is noteworthy that ozone-treated food should be packaged by appropriate methods such as airtight closure or vacuum sealing (Aziz and Ding, 2018).

Hydrogen peroxide (H_2O_2) solutions at 1 and 5% are alternative sanitizer products recommended for mango (Owino and Ambuko, 2021), mainly to reduce gram-positive and gram-negative bacteria (Lopes et al. (2021). This sanitizer is especially effective against *Salmonella spp*., *E. coli* O157:H7, *B. subtilis* and other foodborne microbes, at a dose of <0.3 mg L^{-1} (in vapor form, otherwise it can be phytotoxic). However, H_2O_2 is highly oxidizing, and it requires great caution at handling (Lopes et al., 2021).

Sanitizers that contain calcium, e.g., calcium chloride ($CaCl_2$), calcium carbonate ($CaCO_3$) and calcium citrate ($C1_2H_{10}Ca_3O_{14}$), calcium lactate ($C_6H_{10}CaO_6$), calcium phosphate ($Ca_3(PO_4)^2$), calcium propionate ($C_6H_{10}CaO_4$) and calcium gluconate ($C_{12}H_{22}CaO_{14}$), at a dose of 0.5 - 3% for 1–5 min, are alternative possibilities for FCM (Owino and Ambuko, 2021).

Although the treatment with $CaCl_2$ improved FCM firmness and color more effectively and reliably than untreated samples, calcium treatment did not improve product appeal compared to untreated controls or water-treated FCM. However, consumer appeal was better in $CaCl_2$ treated samples compared to calcium lactate, at 0.136 M calcium solution. The optimal treatment for 'Tommy Atkins' mango cubes was a 2.5-min dip in 0.136 M $CaCl_2$ and for 'Kent' a 1-min dip in 0.136 M $CaCl_2$. 'Kent' mango was more suitable than 'Tommy Atkins' for fresh-cut processing since tissue browning was less intense and the consumer appeal better (Ngamchuachit et al., 2014).

Organic acids (0.5–1% ascorbic combined with 1–2% citric acids) are good alternatives to prevent browning and discoloration of cut slices (Owino and Ambuko, 2021). Acetic acid (vinegar) at a dose of 4% is also an effective antimicrobial solution for FCM (Aldana et al., 2021). Combinations of organic acid with polysaccharide-based edible coatings such as chitosan or alginate can improve the shelf-life and maintain the FCM quality for 15 days (Salinas-Roca et al., 2018a).

Combined effects of multilayer coatings based on sesame protein, guar gum, calcium chloride and mango puree (Sharma et al., 2019) and ascorbic acid + citric acid + $CaCl_2$ (Siddiq et al., 2013) have been shown to be useful in extending the shelf-life of FCM.

15. Natural additives

Sanitizers can reduce the decay rate, but consumers are concerned about chemical residues in the product that could affect human health and cause environmental pollution (Ulloa et al., 2015). Therefore, alternative control methods of fresh-cut fruit decay are required. One of the major emerging technologies for reducing quality loss and increasing the safety of fresh-cut fruits and vegetables is the application of natural additives derived from plants and plant products. They represent a source of natural antioxidants and antimicrobials to improve the shelf-life and safety of food, including fresh-cut fruit (Dahech et al., 2013; Senthilkumar and Venkatesalu, 2013).

The mango seed, one of the byproducts of mango processing, has a strong antioxidant capacity and contains a high concentration of bioactive polyphenols higher than, not only mango pulp and peel, but also seeds from other plant species (Vega-Vega et al., 2013; Bernal-Mercado et al., 2018). Major phenolic compounds found in mango seed extract are tannins, quercetin derivatives, gallic acid, ellagic acid and mangiferin (Dorta et al., 2014). These compounds can neutralize free radicals and inactivate microbial cells. Due to these properties, extracts from mango seeds could be added to FCM, with good results in terms of functionality and antimicrobial protection (Vega-Vega et al., 2013). In addition to the antibacterial and antioxidant benefits of mango seed extract for FCM, the sensorial properties of this additive have been approved (Bernal-Mercado et al., 2018).

Neem (*Azadirachta indica*) seed oil is an antimicrobial substance that can improve the microbiological safety and quality of FCM (Kassé et al., 2017). It reduces firmness and color loss and inhibits the development of the main spoilage bacteria throughout the entire storage period, extending the preservation of FCM fruits (Passafiume et al., 2022).

Soaking in noni (*Morinda citrifolia*) juice is reported to have antibacterial, antiviral and antifungal effects. It has been shown to be a potentially valuable technology of decontamination of FCM surfaces (Ulloa et al., 2015).

16. Non-thermal technologies

Nowadays, consumer demand for clean and safe food without compromising the nutritional and sensory food quality is increasing. This has directed the attention of food professionals toward the development of non-thermal technologies that are green, safe and environment-friendly. By non-thermal processing, food is processed at near-room temperature, so the food is undamaged because heat-sensitive nutritious materials remain intact in the food, contrary to thermal food processing. These non-thermal technologies can be used to treat all kinds of food, e.g., fruits, vegetables, pulses, spices, meat, fish, etc. Numerous non-thermal technologies in the food sector have emerged in the last few decades (Jadhav et al., 2021), e.g., ultraviolet radiation (UV-C), pulsed light (PL), light-emitting diodes (LED), cold plasma (CP), high intensity ultrasound (HIU), neutral electrolyzed (NEW) and acidic electrolyzed water (AEW).

16.1. Ultraviolet- C (UV-C)

Ultraviolet light (UV-C) treatment is a non-thermal technology used as an alternative option for fresh-cut products (Pataro et al., 2015; Garzón-García et al., 2023). Short wavelength light irradiation (100–280 nm) at very low doses of UV-C (minutes to hours) can induce a series of biochemical events within plant tissues, which stimulates the biosynthesis of defensive secondary metabolites with antimicrobial activity (Ribeiro et al., 2012; Pataro et al., 2015; Garzón-García et al., 2023). These compounds are highly desirable because they contribute to prolong the shelf-life and maintain fruit quality by delaying senescence and fruit ripening. In addition, they induce natural defense compounds against fungi and bacteria (Ribeiro et al., 2012). Moreover, the activation of plant defense mechanisms may also stimulate the formation of bioactive compounds with antioxidant potential, increasing the nutritional value of UV-treated products (Ribeiro et al., 2012; Pataro et al., 2015).

In general, disinfecting fresh fruit pieces with UV-C replaces the conventional disinfection method of sodium hypochlorite immersion. This treatment preserves the fruit quality properties and has a less adverse impact on the environment and on the health of consumers since no dangerous chemicals are applied during minimal processing (Castro-Ibáñez et al., 2016; Meireles et al., 2016; Pezzuto et al., 2016).

Disinfection with UV-C (250 nm for 15 min) maintained the quality of FCM ‘Chokanan’ up to 15 days and increased the antioxidant enzyme activities (George et al., 2015). Furthermore, an UV-C treatment of FCM ‘Tommy Atkins’ stored at 5°C for 12 days proved to be effective in preserving microbial safety, total carotenoids, total phenolics and total flavonoids. On the other hand, this treatment decreased fruit firmness (Garzón-García et al., 2023).

16.2. Pulsed light (PL)

Pulsed light (PL) is used to decontaminate surfaces by killing microorganisms (Charles et al., 2013b). It can be an alternative to UV-C (Lopes et al., 2017). Pulsed light is also a non-thermal technology considered a modern evolution of the UV-C technology. The difference consists in the exposure times, which are minutes/hours for UV-C treatments versus seconds in PL treatments (Pataro et al., 2015). The efficiency of PL disinfection is higher than that of UV-C, due to its high peak power along with the ability to deliver energy for short durations, typically 1 to 10 pulses per second (Rowan, 2019). This treatment stimulates higher production of bioactive compounds in plant tissues to minimize the damages caused by high power radiation (Pataro et al., 2015). It has become a promising fresh-cut technology since it can inactivate microorganisms, prolong the product shelf-life and induce changes in quality properties (Charles et al., 2013; Gianpiero et al., 2015; Pollock et al., 2017, Hua et al., 2023). In addition, the very short exposure times required to achieve the desired effects could significantly promote the utilization of PL technology on an industrial scale (Rodov et al., 2012).

PL has been approved by the Food and Drug Administration (FDA) (2017) for the production, processing and handling of food up to a cumulative UV dose of 12Jcm^{-2}. The emission spectra must be maintained between 200 and 1100 nm and the pulses last not more than ≤ 2ms (Rowan, 2019).

Pulsed-light treatments consist of exposing food to intense short pulses (1 μs - 0.1 s), from UV to near infrared (100–1100 nm), emitted by an inert gas (e.g. xenon) lamp (Charles et al., 2013b; Pataro et al., 2015; Rowan, 2019). The light intensity of each pulse is about 2×10^4 times that of the sun at the sea surface (Hilton et al., 2017). Microorganisms are destroyed according to the intensity and number of pulses applied. Inactivation occurs by means of several mechanisms, e.g., chemical modification and cleavage of DNA, protein denaturation and by other alterations of the cellular material (Charles et al., 2013; Salinas-Roca et al., 2017a).

Flashes of PL at 8 J /cm^2 applied to FCM 'Kent' proved effective to maintain the physical and nutritional quality, color and firmness (Charles et al., 2013b). A PL treatment of FCM 'Tommy Atkins' (0.4 J/cm^2, 20 pulses) combined with alginate coating (2 %, w/w) or combined with malic acid (2 %, w/w) and alginate coating (2 %, w/w) reduced *Listeria innocua* counts by 4.5 and 3.9 logs, respectively, with minimal quality deterioration during storage (Salinas-Roca et al., 2016). Treating FCM 'Tommy Atkins' with PL (0.4 J/cm^2, 20 pulses) combined with alginate coating (2 %, w/w) or combined with malic acid (2 %, w/w) and alginate coating (2 %, w/w) prevented browning during storage at 4 ^{o}C for up to 14 days. This treatment also increased antioxidant contents, including mangiferin, and increased phenolic compounds (Salinas-Roca et al., 2018b). In PL treatments, the light application mode is more important than the fluence or final dose applied to FCM. Results indicate that four successive pulses (0.7 J /cm^2) were more effective than one pulse per day for 4 days to maintain the FCM sensory quality. The differences in this case were related to the degree of structural damage produced by each pulse dose (Lopes et al., 2017).

16.3. Light-emitting diode (LED)

In view of their antibacterial effect, light-emitting diodes (LEDs) at visible wavelengths have gained attention as preservation technology (Kim et al., 2017). Previous studies showed that under refrigerated conditions, blue LEDs of 405 and 460 nm could inactivate various foodborne pathogens, e.g., *E. coli* O157:H7, *L. monocytogenes* and *S. Typhimurium* (Ghate et al., 2013; Kim et al., 2015, Kim et al., 2016).

An FCM treatment with 405 ± 5 nm LED illumination effectively inactivated 97–99% of *E. coli* O157:H7, *L. monocytogenes* and *Salmonella spp*., but was less effective to destroy *L. monocytogenes* and *E. coli* O157:H7 at room temperature (Kim et al., 2017).

16.4. Cold plasma (CP)

Cold plasma (CP), a non-thermal treatment technology safety and high efficiency, have shown no or minimal impacts on the physical, chemical, nutritional and sensory (Pankaj et al., 2018) and has attracted increasing attention from agriculture and food industries (Sruthi et al., 2022).

Plasma is the fourth state of matter and has a high-energy system that contains diverse reactive species, including molecules, atoms, ions, electrons, free radicals, photons, and visible light, providing physical and chemical interactions with food components, contributing to the improvement of food security and health (Saremnezhad et al., 2021). In practice, CP can be created in several different ways, including glow discharge, corona discharge, radiofrequency discharge, dielectric barrier discharge (DBD), microwave discharge and cold plasma jet (Asl et al., 2022; YI et al., 2022).

The oxidative species released via CP treatment function as disinfectants to trigger membrane lipid peroxidation and damage proteins and nucleic acids of microorganisms on the food (Saremnezhad et al., 2021). In addition, the CP treatment can potentially alter metabolic features and strengthen the endurance capacity of fresh agricultural products regarding senescence and adverse environmental stresses (Sruthi et al., 2022).

Antioxidants can protect lipids and increase their oxidative stability when food is subjected to plasma reactive species. They suppress free radicals, bind oxygen, and prevent oxidation, thereby preserving food quality. The significant antioxidants and scavenging compounds present in fruits and vegetables are phenolic compounds, vitamin C, and vitamin E. Though antioxidant activity is not an exact indication of quality in the food industries, it closely points to the various polyphenols, flavanols, and flavonoids present in foods (Pankaj et al., 2018). These bioactive compounds show the ability to scavenge free radicals accountable for sundry infections and diseases often triggered by oxidative stress and thus minimize their threat (Sruthi et al., 2022).

The CP treatment (75 kV, 3 min) applied to FCM markedly inhibited the increase in total microbial counts, improving food safety. Moreover, it intensified antioxidant enzyme activities and delayed the deterioration of sensory and nutritional qualities (YI et al., 2022).

16.5. High Intensity Ultrasound (HIU)

High-intensity ultrasound (HIU) processing has become a response to the ever-increasing demand for high-quality, convenient meals with natural taste, without addition of chemical preservatives (Chavan et al., 2022). The technology is based on the application of low-frequency ultrasound (20 to 100 kHz) at high intensity (10 to 1000 W/cm^2) (Wang et al., 2021). It is used to modify physical, biochemical, and mechanical properties of food products by acoustic cavitation that increases temperature and pressure, among other mechanisms (Muñoz-Almagro et al., 2021). High-intensity ultrasound is an alternative to thermal processes, which are frequently associated to a loss of sensory and nutritional characteristics (Fernandes and Rodrigues, 2009). It has considerable ability to maintain the high quality of food by inhibiting microbial contamination (Aadil et al., 2018; Zia et al., 2019) by breaking down the microbial cell wall (Birmpa et al.,

2013) and inhibiting enzymes that control degradation actions such as pectin methylesterase, peroxidases and PPO (Santos et al., 2015; Aadil et al., 2020). HIU also preserves the fresh-looking color (Ranjha et al., 2021) and surface characteristics of fresh-cut food products (Giannakourou and Tsironi, 2021; Roslia et al., 2022).

In the HIU treatment of FCM 'Tommy Atkins', with sonication at 25kHz and 55W/cm^2 for 30 min and cold storage for 7 days at 4 °C, the results of microorganism inactivation were not satisfactory, and the fruit quality was negatively affected (Santos et al., 2015). However, HIU applied to FCM 'Kent' was reported to be a more effective technique for browning prevention, with lower PPO activity than the chemical (ascorbic acid and calcium chloride agents) and physical (immersion in hot water) applications. This technology also prevented color degradation, improved the bioactive content (ascorbic acid, antioxidant capacity and total phenolics) and maintained sensory properties (Yildiz and Aadil, 2022).

16.6. Neutral electrolyzed (NEW) and acidic electrolyzed water (AEW)

Neutral electrolyzed water (NEW) and acidic electrolyzed water (AEW) are alternative technologies to chlorinated sanitizers with antimicrobial activity (Rahman et al., 2016) for a range of pathogenic microorganisms (Ovissipour et al., 2015; Santo et al., 2018; Lopes et al., 2021). With respect to bacteria, electrolyzed water can destroy bacterial DNA or disrupt its synthesis. Regarding fungi, it oxidizes the cell wall, disrupts the metabolism of organic compounds and even resistance and survival structures are eliminated (Rahman et al., 2016). Acidic electrolyzed water can be produced with a pH between 2 and 4 (Vásquez-López et al., 2021) and neutral electrolyzed water can have a pH between 6 and 9 (Rahman et al., 2016).

According to Vásquez-López et al. (2021), NEW has several advantages, such as: a) greater stability of chlorine agents and safety for consumer health

(Hamidi et al., 2020) since NEW can be reverted back to water and salt, without an excessive release of toxic substances (Ramírez Orejel and Cano-Buendía, 2020), b) potential for reducing pesticide residues on fresh produce (Han et al., 2017; Hu et al., 2016; Qi et al., 2018), c) no residues of NEW on the fresh produce after application (Rahman and Murshed, 2019), d) no cross-contamination resulting from handling, transportation and packaging (Afari et al., 2015) and e) it has been reported that NEW has no negative effects on the physical, organoleptic and nutritional qualities and chemical components of fresh produce (Hao et al., 2015; Aday, 2016). However, the main disadvantage of EW is that its effectiveness is reduced in the presence of organic compounds, which weakens its antimicrobial capacity (Duan et al., 2016). Acidic electrolyzed water has been less frequently recommended because at such a low pH, dissolved Cl_2 gas can be rapidly lost due to volatilization and the bactericidal activity of the solution decreases with time (Len et al., 2000). In addition, the strong acidity may cause corrosion of equipment and consequently limit practical applications (Guentzel et al., 2008).

The microbiota of fresh-cut 'Tommy Atkins' mango treated by immersion in NEW solutions (0, 75, 150, 225 and 300 mg L^{-1}) or chlorine-based product at 200 mgL^{-1} stored at 3 ± 2 °C, 85 ± 5% RH for 0, 6 or 12 days, respectively, was similarly reduced by NEW treatments as by sanitization with commercial product. Nutritional components such as vitamin C, carotenoids and phenolics were preserved by both NEW treatments and commercial chlorine. In terms of the sensory aspects, NEW (150 mgL^{-1}) presented the same good acceptability as observed for commercial chlorine and even lower off-flavor intensity than the chlorine-based sanitizer (Lopes et al., 2021).

Escherichia coli and *C. sakazakii* were not able to grow on FCM 'Tommy Atkins' maintained at 4ºC, 8 ºC and 12 ºC. However, at 20 ºC, exponentially growth of *E. coli* and *C. sakazakii* was observed in less than 72 h and 48 h, respectively Santo et al. (2018). Although both species had a similar growth pattern on FCM, they were differently affected by the decontamination methods tested. *Escherichia coli* was more sensitive to the chemical methods and *C. sakazakii* to the physical method tested. The use of UV-C (5, 7.5 and 10 $kJ.m^{-2}$)

reduced *C. sakazakii* by more than 2 log cfu/g, while AEW, NEW and sodium hypochlorite (SH) resulted in smaller reductions. The contrary was observed for *E. coli*, whose population was more efficiently reduced, by 2 log cfu/g, when AEW, NEW and SH were used, than by the physical method. The results highlighted the importance of understanding the differential survival strategies of the microorganisms to protect themselves as well as the food matrices when studying and testing different decontamination technologies. It is also worth bearing in mind that good agricultural and manufacturing practices and efficient refrigeration chains should never be neglected (Santo et al., 2018).

17. Modified atmosphere (MA) and packaging

Despite the effectiveness of antioxidants and the antibrowning and/or firming products, some consumers demand a further reduction in the use of chemical methods for shelf-life extension of fresh-cut fruits (Montoya et al., 2019) and a modified atmosphere (MA) is another approach to this goal.

The MA, with low O_2 and elevated CO_2, has been created to reduce the respiration rate and water loss. It has been used to extend the shelf-life with good sensorial results. It helps altering the gas composition within a food packaging system. A modified atmosphere relies greatly on the relation between the respiration rate of the produce and gas transfer through the packaging material without any artificial alteration of the initial gas composition. A MA can either be passive: in this case, a MA is generated in a packaging material by relying completely on the natural respiration process of the packaged produce as well as the permeability of the packaging film material to establish the desired gas composition. A MA can also be established actively, by replacing the gaseous composition in a packaged material by the introduction of gas scavengers or absorbers such as ethylene scavengers, oxygen and carbon oxide, thereby establishing the preferred gas mixture within the package (Jideani et al., 2017).

The use of plastic protective films is increasing due to their accessibility and ease of manipulation. These types of packaging can extend the shelf-life of fresh-cut fruits by reducing moisture, respiration and physiological changes and by preventing changes in aroma, taste, texture and appearance (Montoya et al., 2019). A MA provided by packaging in traditional polymeric film (oriented polypropylene, OPP) or biologically-based film (poly lactic acid, PLA) combined with HT is a promising option to preserve FCM quality (Charles et al., 2013a).

The increasing environmental awareness associated with a greater concern about the impacts of the disposal of synthetic packaging has been stimulating countless studies on biodegradable polymers worldwide (Qadri, 2915; Montoya et al., 2019). However, although the first biodegradable polymers of synthetic origin or from renewable sources have been developed approximately 40 years ago, their use and commercial applications are still limited, not only because of the high costs of these materials but also due to the difficulty of processing them on an industrial scale. Compared with the properties of most non-biodegradable synthetic polymers, biodegradable polymers are rather limited (Leal et al., 2019). Still, ecofriendly materials based on polysaccharides such as starch, alginate and cellulose can be useful for packaging (Montoya et al., 2019).

A formulation of biodegradable packaging containing cassava starch and poly (butylene adipate-*co*-terephthalate) flexible films was considered a viable alternative for FCM storage. The films were developed and extruded at different proportions of cassava starch: PBAT: glycerol with and without green coconut fiber (nanocrystals), annatto and citric acid. The best formula for FCM for 14 storage days contained cassava starch, PBAT, glycerol, nanocellulose, annatto, citric acid (40: 60: 20: 0.55: 0.5: 1.0g). However, the action against microbial agents and antioxidant action to prolong the shelf-life of the product should be further investigated (Leal et al., 2019).

Despite the ecofriendly characteristics of polysaccharide-based films, some of these, such as starch-based films, have poor mechanical properties due to retrogradation effects related to the reassembling of solubilized starch granules. This phenomenon can be controlled by starch modification, blending with other materials, or reinforcing with renewable biodegradable materials

(Balakrishnan et al., 2018). Both bacterial (BC) and vegetal cellulose (VC) have good mechanical properties; thus, they can be used to reinforce thermoplastic starch (TPS) films, known as bacterial cellulose nanoribbons (TPS/BC) (Montoya et al., 2014; Montoya et al., 2019).

A thermoplastic starch (TPS) and its composites with bacterial cellulose nanoribbons (TPS/BC) was used as wrapping material to prolong the shelf-life of FCM. Results showed that TPS films reduced mango weight loss until the fifth day (2.84%), whereas the reduction in weight loss in mango wrapped with TPS/BC was even lower (13.18%). Therefore, even though both TPS and TPS/BC films can be used to prolong the fruit shelf-life for five days, the latter being more effective (Montoya et al., 2019).

The widespread use of polyvinyl alcohol (PVA) film is significantly hindered by two marked limitations: water sensitivity and low gas permeability. Liu et al. (2023) tested a novel PVA film coated with monoglyceride (MG) and filled with diatomaceous earth (DS). This PVA/ MG/DS proved promising as ecofriendly packaging material for FCM.

Active packaging technologies seem to be a promising solution to extend shelf-life, owing to their capability to directly interact with the food and/or the surrounding packaging atmosphere, by releasing protective substances or absorbing others that accelerate decay (Apicella et al., 2018a; Apicella et al., 2018b). Among these, oxygen scavengers, antioxidants and antimicrobials are the most interesting and promising active systems, since they deeply affect the quality preservation and extension of the shelf-life of foodstuff. When oxygen is removed from the medium by oxygen scavengers and antioxidants, oxidation reactions, such as lipid oxidation and enzymatic browning, decrease (Apicella et al., 2019a). Antimicrobials, on the other hand, can kill or inhibit the growth of pathogenic microorganisms that may contaminate packaged food products, avoiding a direct application of chemicals on the food surface (Apicella et al., 2019b).

Wrapping FCM in 40 µm active layer films that contained an oxygen scavenger limited color change by 32–36% but decreased pulp firmness after 7 days of storage at 4°C. The use of active packaging proved promising but requires further testing and possibly combinations with other physical or chemical treatments (Leneveu-Jenvrin et al., 2021).

Bacteriocins are small antimicrobial peptides synthesized by bacterial ribosomes, active against the bacterial pathogen (Aljohani et al., 2023). They have been used for food preservation in active packaging and represent a potential alternative for the preservation of fresh-cut fruits. Nisin is a bacteriocin with high antibacterial activity, stable at an acidic pH, unable to cause changes in the food product and relatively little toxic to humans. For FCM, nisin- anchored cellulose films had antimicrobial activity against *Staphylococcus aureus, Listeria monocytogenes*, *Alicyclobacillus acido terrestris* and *Bacillus cereus,* and did not interfere with the sensory characteristics (Barbosa et al., 2013).

The application of 1-MCP (1µL. L^{-1}), an ethylene inhibitor to FCM decreased ethylene production and, consequently, symptoms of water-soaked appearance. In addition, the product also diminished aerobic bacteria, yeast, and mold growth. This ensured product safety for consumption according to European Union standards, after 7 days of refrigerated storage (Castillo-Israel et al., 2015).

18. Conclusions

Very few alternatives have been sought to increase the FCM quality and shelf-life to meet the consumers' demands. Despite the difficulties with mango breeding, plant breeders could benefit more from the genetic variability in the species, addressing FCM quality. Sensory evaluations to understand the consumers' preferences are essential and should be done more frequently in FCM research. As far as we know, no field research on agronomic practices that could contribute to FCM quality has been published. Neither have the optimum FCM storage temperatures been studied in depth, with a view to simultaneously maintaining the sensorial quality and keeping the product microbe-free for a longer shelf-life period. In view of the relevance of FCM and perspectives of increasing its consumption, new ecofriendly technologies, such as natural additives and non-thermal treatments that can control foodborne microorganisms replacing sanitizers, and packages made of biodegradable raw materials, have been insufficiently studied so far.

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CORRESPONDING AUTHOR

Francine Lorena Cuquel
<flcuquel@gmail.com>

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Cornelia Elisabeth Abreu-Reichart

Rua Lovinia Pratti 243/ Bairro Sta Rita
29255-000 Marechal Floriano – Espírito Santo - BRAZIL