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MINIMALLY PROCESSING AND PRESERVATION METHODS FOR SHELF-LIFE PROLONGING OF DIFFERENT TYPES OF FRUITS

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Abstract

Minimally processed fruits are characterized by a short storage period, due to their high sensitivity to microbial and physico-chemical alteration due to the increased respiration rate and more ethylene production, which stimulates the overripening and the injury of the fruit tissue. Moreover, microbial alteration may present a food safety risk for the end consumers, fruits mostly being consumed in raw state. In addition, consumers have become more critical regarding the use of synthetic food additives utilized to increase the shelf life or to improve some sensorial characteristics of the fruits. Controlled temperature and hygiene of the whole supply chain offers the necessary conditions to maintain the quality of the products and to stop the alteration and cross contamination with pathogenic microorganisms. Because fresh fruits shelf life very much depends on certain temperatures and relative humidity parameters, to avoid spoilage, they must be handled properly during all the stages prior to their commercial points. The storage time of the majority of fruits is determined by changes in their sensorial characteristics and, therefore, in order to extend the shelf life and maintaining good quality, farmers and processors must keep the them at the optimum storage conditions that could be specific to each specie and variety.

Key words: *fruits, preservation, quality, shelf-life.*

INTRODUCTION

Fruits are known to be an essential part of the dietary human needs, as they are a major source of vitamins, minerals, carbohydrates and fibres, thus their consumption has been linked with several health benefits (Ma et al., 2017; Yousuf et al., 2018). The shelf life of a food product can be defined as the period in which it can be consumed without being harmful to the human health and its physical, chemical, microbiological and organoleptic qualities remain unchanged. Therefore, in order to extend the shelf life of various types of fruits, various preservation methods, regulations and rules have been established and must be applied by both producers and retailers (Yousuf, 2018). There are three major categories of preservation techniques used nowadays in order to extend the shelf-life of fruits: bio-preservation, physical-based and chemical-based preservation technologies (Ma et al., 2017). In order to maintain or extend the shelf-life of food products through physical-based technologies, temperature, pressure, gas composition and humidity are strictly monitored and modified taken into consideration the food product that is being packaged (Krasaekoopt & Bhandari, 2010). Bio-preservation techniques include the use of natural antimicrobial agents, such as plant extracts, and chemical-based solutions use synthetic additives in order to extend the shelf-life of fruit products (Liu et al, 2020). In recent years, there has been a development for innovative preservation technologies, such as pulsed electromagnetic field (Cao et al., 2019), cold atmospheric plasma, ultrasound treatment, modified atmosphere packaging or edible coatings (Giannoglou et al, 2021; Yildiz et al, 2021). In this review study, the most perishable types of fruits will be discussed and the actual preservation methods for shelf-life prolonging will be outlined for each type of fruit.

1. PRESERVATION METHODS AND SHELF-LIFE FOR APPLES

Apples are being consumed all over the world, all year round, thus making them one of the most economically important fruit in the world (FAO, 2017). The most common technique used to extend the shelf-life of apples is preserving them in cold storage, however over time, some quality losses may appear (Zhang et al., 2021). One of the key factors for maintaining their nutritional and organoleptic qualities during the storage period is determining a correlation between harvest maturity and the temperature of storage (Juhnevica-Radenkova et al., 2014; Zhang et al., 2021). da Rocha Neto et al., (2019) studied the effect of a double-bottom antimicrobial packaging used to extend the shelf-life of apple samples, by inhibiting the growth of *Penicillium expansum*. The results showed that the inoculated apple samples that were stored in the developed packaging material containing palmarosa essential oil had 1/3 less fungal growth, as well as less than 50% ethylene and CO_2 production. Ultrahigh hydrostatic pressure (HPP) apple juice samples were studied by Juarez-Enriquez et al., (2015) in order to observe the treatment influence over the shelf-life of the treated samples. Several parameters such as, ascorbic acid content, pH, titratable acidity, total soluble solids, polyphenol oxidase and pectin methylesterase were determined in the treated and control samples. The results indicated that the HPP treatment preserved the physicochemical parameters, as well as extended the samples shelf-life.

2. PRESERVATION METHODS AND SHELF-LIFE FOR GRAPES

Grapes (*Vitis vinifera* L.) is a worldwide spread fruit crop, with uses in many industries that possess a low physiological activity (Youssef et al., 2020). Because the table grape demand is increasing early, novel processing and preservation technologies are emerging very fast. Because of the high water content and nutrient composition, grapes are an ideal growth medium for fungi, especially *Botrytis cinerea* (Hernandez-Montiel et al., 2018). The main method for inhibiting the growth of fungi is applying chemical fungicides, however this technique is not sustainable, nor environmental friendly (Khalil Bagy et al., 2021). Shahkoomahally et al., (2021) studied the effect of modified atmosphere packaging (MAP) on extending the shelf-life of Muscadine grape (*Vitis rotundifolia* Michx). Grape samples were stored at 4°C and 95% relative humidity for a period of 42 days, in either air or MAP with different percentage of O_2 and CO_2 (6% O2 + 10% CO2), or (4% O_2 + 30% CO_2). The results showed that the samples packaged in MAP presented an improved preservation of compositional quality and delayed softening.

3. PRESERVATION METHODS AND SHELF-LIFE FOR BERRIES

The most perishable fruits on the market are berries, because of their high water content and short shelf-life. The berries market is growing from year to year, hence implying a great research effort in this field so that the producers can offer a longer shelf life and a higher quality for these types of fruits. However, the processing of berries can lead to several changes in the fruits: biochemical, the loss of texture and nutritional value and microbial contamination (Katsaros et al., 2015).

Berries are cultivated on different types of soil, through different technical and agricultural technologies. Some actions during cultivation and harvesting may favour the development of different types of microorganisms that can contaminate the fruits (Toivonen & Brummell, 2008; Paulsen et al., 2021). Due to the action of microorganism, it is estimated that about 30 % of berries stored at improper conditions deteriorate and therefore cannot be sold by the producers. Yearly, the harvest of berries records significant oscillations, as a result of the natural climatic conditions and inappropriate management. Such negative phenomena are accentuated by the high degree of perishability of many species and varieties of the berries (Yildiz et al., 2021). The development of microorganisms on berries is slow, but nevertheless, the microorganisms penetrare into the internat tissues of the fruit, becoming difficult to visually observe during the early stages. Some of the microorganisms, especially micromycetes of some species belonging to *Penicillium* and *Aspergillius* genus, are able to produce secondary metabolites of various compositions, which are toxic to the human health (Drusch & Aumann, 2005). It has recently been found that various alphatoxins, ochratoxins, fumigaciones, rugulosins, patulin, emodin, zearalenone, trichothecene, and other toxic compounds produces by certain species of micromycetes are particularly dangerous to human health (Mandappa et al., 2017).

Blueberries

Blueberries (*Vaccinium corymbosum)* are highly appreciated for their nutritional and medicinal proprieties (Defilippi et al., 2017). The marketing of this high value fruit crop is affected by a number of fungal and bacterial microorganisms (Liato et al., 2017). The shelf-life of blueberries can be maintained through a temperature controlled supply chain, where temperature monitoring and management are vital. In the food industry, deterioration occurs mainly in fresh products due to their short lifespan and perishability. Fresh food requires adequate temperature control through the technology chain. Unlike other products, blueberries need a strictly controlled temperature during the storage and transport processes. Proper and careful management of the temperature along the harvesting and marketing chain is essential for maintaining the quality of blueberries (Paniagua et al., 2014).

Blueberries can be stored for 2 to 4 months at a minimum recommended temperature of 2°C and a maximum recommended temperature of 4 to 5°C. The optimum relative humidity (RH) level is 90-95 %. After harvesting, blueberries are firm and have a thick layer of protective wax, so great care must be taken during the harvesting process, to insure they do not suffer any physical damage (Perkins-Veazie et al., 2008). However, they have a great variability in their shelf life, even in refrigerated conditions.

An earlier harvesting of the blueberries extends their shelf life. This variability in storage life can be reduced by good management of the temperature in the storage rooms, but also by the use of appropriate fungicides. The cold storage temperature is up to 3.3°C, and, at this temperature, the degradation of the berries is delayed, but nevertheless, long term storage is done at lower temperatures, around -1°C to 0.6°C (Nunes et al., 2004).

The dynamic of blueberry respiration plays a major role and affects the shelf life of the fruits because the respiration provides all the energy needed for the biochemical processes (Palanimuthu et al., 2007; Chen et al., 2021). Reducing the respiration rate by changing the storage conditions by lowering the temperature or changing the composition of the gases can significantly increase the shelf-life of berries (Bell et al., 2021**)**. However, there are a series of factors, such as the type of fruit, variety, the degree of maturity, storage time after harvesting, that have also been reported as potential factors affecting blueberry fruits respiration rate (Fonseca et al., 2002). Recently, several studies have investigated the use of high field voltage (HVEF) in drying fresh fruit to improve shelf life (Kao et al., 2019; Lotfi et al., 2022). A number of studies have reported an increase in drying rates for certain fruits and vegetables, for example, potatoes (*Solanum tuberosum)*, radishes (*Raphanus sativus* L.), spinach (*Spinacia oleracea* L), paddy rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) using single of multiple HVEF systems. However, the mechanism by which respiration is controlled by HVEF is not yet well defined and further studies are needed to describe the mechanism and its long-term effects on food (Palanimuthu et al., 2007). As this method of treatment does not consume significant amount of energy, it can be used to improve the shelf life of blueberries, without affecting the quality of the fruit (Kuriya et al., 2020)

Raspberries

Raspberries (*Rubus idaeus),* have a short shelf-life, and the main way of maintaining it is through the maintaining the temperature between 0-2°C and the relative humidity between 90-98% (Huynh et al., 2019).

Fresh raspberries are in high demand in Europe and in other parts of the world. The main constituent of raspberries is water (approximately 87%). Pectin is present in 0.1-

1.0%, but this percentage decreases with the ripening of raspberries due to the process of hydrolysis. The main sugars that are present in the fruits are glucose, fructose and, in small amounts, sucrose. They make up the major soluble component of raspberry juice. A ripe raspberry fruit contains between 5 and 6% sugar. Raspberries also contain small amounts of citric acid and malic acid (Bowen-Forbes et al., 2010). The amount of acid increases in the fruit at the beginning of the fruit growing period, and then decreases once the fruit begins to ripen. The balance between sugars and acids is important for raspberries to taste good and to be accepted by consumers. A fruit with a low sugar content will have a high acid ratio and therefore, a sour taste. The usual pH of ripe raspberries is 3.0 – 3.5; the ratio of sugars and acids (w/w) is about 1.0. Fruits grown in hot, dry summers (daytime temperatures close to 25°C) are sweeter, less acidic, have a stronger flavour, and more strongly coloured. Excessive heat (temperatures above 30°C) will reduce the fruit flavour, and wet weather will reduce the sugar content (de Souza et al., 2014).

Raspberries have one of the highest respiration rates of all berries. This aspect, along with their thin skin makes them very perishable compared to other berries. The optimal stage of maturity for raspberries occurs when berries turn completely red (Gonzalez et al., 2003).

The conditions under which the breathing process can be slowed down are storage at low temperatures, combined with high levels of carbon dioxide and small amount of oxygen in the storage room. The process of respiration is slowed down by high humidity. For raspberries, it is very important to maintain an atmospheric humidity of 90-90%, simultaneously with the low temperature in order to prevent the water loss from the fruit. Special cooling units designed to maintain a high humidity for raspberries are required. At 25°C and 30% relative humidity, fruit loses water 35 faster than at 0°C and 90 % relative humidity (Ozcelik et al., 2020).

Substances that have the ability to act as antimicrobial agents naturally prolong the shelf life of berries have been sought. One such natural compound is chitosan, obtained from the partial deacetylation of chitin, which is a polysaccharide (Kim et al., 2011). Chitosan is one of the most promising coatings for fresh produce due to its excellent coating, broad antimicrobial activity and compatibility with other substances (Kaya et al., 2016). The shelf life can be conditioned either by controlling the agents (growth of microbial populations, enzymatic activities, concentration of reactive compounds) or by monitoring their effects, such as changes in pH, aroma, texture, nutritional value, and the presence of specific compounds, mainly in the early stages. Another way to extend the shelf life is to cover foods with sodium alginate, pectin, and gelatine. They have been shown to be effective, not only in the way they delay water loss (Vimala et al., 2011; Joshi et al., 2021). There is an interest in the use of natural antimicrobials, as they have fewer side effects and have a better biodegradability compared to other available food preservatives (Campos et al., 2011; Kalemba & Kunicka, 2003). These compounds can be extracted from plants or essential oils. Only a few studies have been published on the efficacy of these compounds when incorporated into edible layers applied on fresh fruits (Campos et al., 2011; Rojas et al., 2007).

Raybaudi-Massilia et al., 2008, investigated the use of edible alginate based coatings in which they incorporated malic acid and essential oils of cinnamon, palmarosa and lemongrass on fresh cut melon (*Cucumis melo).* The coating containing 0.3% palmarosa oil appeared to be a promising preservation alternative, as it had received a good acceptation by panellists, maintained the food quality parameters and inhibited the growth of the native microflora and reduced the population of *Salmonella enteritidis.*

A new method of extending the shelf life of berries is to submerge them into various solutions contained polyelectrolytes charged with an opposite electric charge. Antimicrobial coatings with this technique have proved to be successful in treating papaya and pineapple fruits. However, further testing of the coating composition is still necessary due to problems with texture and flavour (Mantilla et al., 2013).

Strawberries

Strawberries (*Fragaria x ananassa)* are well known for their flavour and nutritional value. The quality of strawberries is defined by the intrinsic properties: appearance (color, size and shape), firmness, taste and high antioxidant content of fruits (Di Vittori et al., 2018). Strawberries have one of the most complex aromas of the berries and consists of about 350 volatile compounds (Schwab et al., 2008).

Strawberries are a source of compounds beneficial to human health, such as phenolic compounds, of which anthocyanins are the most abundant. The phenolic content of strawberries is highly variable, mainly due to differences in cultivation, growing conditions, maturity (Tian et al., 2017; Di Vittori et al., 2018).

The fruit skin of the strawberries is extremely thin and the flesh is very soft, therefore, they have a short shelf life of around 7 days (Ayala-Zavala & et al., 2004).

Studies indicate that the optimum storage temperature for strawberries is 0°C to 2°C, a temperature that does not cause the freezing of the tissue and minimizes the alteration of the fruits (Ayala-Zavala & et al., 2004; Aamer et al., 2021). Besides lowering the metabolic processes, storing the fruits at a low temperature also inhibits the growth of molds. The optimum humidity for their storage in order to prevent water loss and wrinkling is 90 to 95% (Di Vittori et al., 2018).

Ikegaya et al. (2020) studied the effect of the storage temperature in the presence or absence of film packaging on two varieties of Japanese strawberries. Storing the fruits at 0°C suppressed the spoilage and the reduction in sugars and organic acids compared to storage at 3°C. However, without the film packaging, storage at both 0°C and 3°C decreased the fresh weight, which results in a loss of quantity. The reduction of weight was lowered to <5% after 28 days by packing the fruits in film packaging. Modified Atmosphere Packaging (MAP) is a post-harvest technology used to extend the shelf life of fresh fruits and vegetables. In this technique, high concentrations of CO_2 and low concentrations of O_2 are often used to slow down the respiration process of the respiration process of the packaged product (Church et al., 1995; Sivertsvik et al., 2002).

Blackcurrant

Blakccurrants (*Ribes nigrum* and *Ribes rubrum)* are perennial plants that are part of the genus *Ribes*, along with gooseberries (*Ribes uva-crispa)*. Their fruits are covered with a protective layer of wax that protects the them form physical damage that can occur both during the growing season and during harvesting. The taste is sweet when the fruits are ripened, with variable acidity (Bakowska-Barczak et al., 2011).

Blackcurrants contain vitamin B, P, E, A, phosphorus, iron and potassium. Vitamin C is particularly valuable in these fruits. To ensure the daily recommended dose of vitamin C, it is enough to consume 20 berries of blackcurrant (Rubinskiene et al., 2005). In red currant (*Rubus rubrum),* the level of vitamin C is slightly lower compared to blackcurrants, but instead, red currants have a higher content of iron, potassium and vitamin P. Blackcurrant and redcurrant normalize the activity of the cardiovascular system and strengthen the blood vessels. Red currants helps a lot in detoxifying and lowering blood cholesterol (Barre, 2001).

Blackcurrants fruits need to be handled with great care, in order to not damage the natural protective coating and it is necessary to maintain the optimal temperature during transport. The boxes in which the currants are harvested should not be left exposed in the sun, as the temperature of the fruit can rise above the air temperature in less than one hour.

Research has shown that cooling currants with forced air at a temperature of 0°C within 2 hours showed a lower degree of degradation (37-46%), after storage for 10 days at -0.5°C, compared with the currants that have been cooled to 1.5°C for 48 hours (Mäkilä et al., 2017). Rapid heat dissipation with forced cold air is referred to as the pre-cooling or pressure cooling stage. After currants are cooled, they can be left in the cold room until they are packaged for their sale in stores. As with other small fruits, currants should be stored in high humidity (95 % at – 0.5°C. Harvested with great care, pre-cooled and stored at 0°C, the currants can reach a shelf life of about 14 days (Osokina et al., 2021).

Blackberries

Blackberries (*Rubus* spp.) are juicy, sweet berries and are considered a summer delicacy. Blackberries are very low in calories. 100 g of fresh blackberries contains only 43 calories.

However, they are rich in soluble and insoluble fiber (100 grams of fruit contain 5.3 of fiber or 14% of the daily recommended dose). Xylitol is low calorie sugar substitute in blackberries. It is absorbed into the bloodstream at a slower rate than glucose, helping stabilize blood sugar levels (Jiao et al., 2005).

Blackberries contain high amounts of phenolic flavonoids, such as anthocyanins, ellagic acid, tannins, gallic acid, cyanidin, pelargonidin, catechins, kaempferol and salicylic acid. Scientific research has shown that these antioxidant compounds may benefit human health and fight cancer, aging and neurological diseases (Hassimotto & Lajolo, 2011). Fresh blackberries are an excellent source of vitamin C, which is a strong natural antioxidant. Eating fruits that are rich in vitamin C helps to develop resistance against infectious agents, against inflammation and helps cleanse free radicals in the human body.

Blackberries can be stored for 2 to 5 days at – 0.6 to 0°C, with a relative humidity of 90 to 95%. Red blackberries gradually darken in colour and turn blue if they are stored for more than 8 days. It should be noted that when stored at 0°C, the colour does not change prominently as when storing blackberries at 4°C (Horvitz et al., 2017). Blackberries must be handled and transported with special care to avoid damage. It is recommended that 15-20% CO_2 should be added into the trucks during the transportation, in order to delay the softening and the degradation effect. Sometimes dry ice is used to supply carbon dioxide.

Blackberries are very perishable, but if they are to be eaten on the same day, they can be stored safely at room temperature (24 to 25°C). The berries are best stored at 1 to 3°C in the refrigerator (Soliva-Fortuny, 2010).

Gooseberries

Gooseberries (*Ribes uva-crispa)* are very perishable and their shelf life is quite short. It can be increased by rapid cooling after harvest. Fruits should be refrigerated at about 1°C within 2 hours of harvesting. Cooling requires a refrigerator with adequate cooling capacity and a fan system so that the cold air can circulate through the pallets of berries (Barney & Hummer, 2004).

Cranberries

Cranberries (*Vaccinium macrocarpon)* are small, red berries that contain significant amounts of vitamins that are beneficial to the human body (Jepson et al., 2012). These are closely related to blueberries (*Vaccinium corymbosum)*, belonging together in the same genus. Fruit ripening begins in mid-summer and the second harvest ripens in late September. Because cranberries are closely related to blueberries, they share a similar nutritional content; they are a good source of vitamin C, contain anthocyanins, about 100 mg per 3.5 kg of fresh fruits (Côté et al., 2010). Anthocyanin, a type of flavonoid, is a powerful antioxidant and it present in cranberries. Research suggests that these antioxidants help reduce the risk of heart disease and the risk of cancer. Anthocyanins help prevent the oxidation of cholesterol in the blood (Hancock et al, 2008).

Cranberries contain high levels of benzoic acid, which naturally offers a longer shelf life. The harvested and cleaned berries can be stored for 3 to 5 weeks before the delivery. Refrigeration at 0 °C will keep the cranberries at an optimum quality (Forney, 2003).

In order to lower the respiration rate, Palanimuthu et al., 2007 used high voltage electric fields (HVEF) of 2, 5 or 8 kV cm^{-1} for 30, 60 or 120 minutes on cranberry fruits. After treatment, the berries were stored at ambient conditions (23°C and 65% RH) for three weeks. After two or three weeks storage, the HVEF treated fruits showed significant lower respiration rates.

CONCLUSIONS

Storage in optimal conditions after harvesting fruits is very important because, after harvesting, the metabolism continues. The shelf life differs from the expiration date. The shelf life is related to the quality of the food products, while the expiration date refers to the safety of the food. The shelf life can be influenced by many factors: light and heat exposure, transmission of gases (including moisture), mechanical stress and contamination with microorganism.

Shelf life is a very important factor for human health. Bacteria and microorganisms are everywhere, and the food that is not properly stored can become contaminated with various types of microorganism that may produce secondary metabolites that are toxic to consumers, especially that fruits are usually eaten raw. It is important that each type of fruit is handled and stored according to their optimal parameters in each stage prior to their selling in stores, to ensure the final consumer not only benefits of unspoiled fruits, but also that the fruits maintain their organoleptic characteristics and their nutritional value.

The most used technique to extend the shelf life of fruits is cold temperature preservation, with controlled relative humidity and CO_2 levels, but new research suggests that other methods, such as the use of antimicrobial additives, pulsed electromagnetic plasma, ultrasound treatment, modified atmosphere packing or edible coating are also efficient in maintaining the nutritional values and organoleptic characteristics and inhibiting the growth of microorganisms of fruits.

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