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Active ingredients in edible coatings for tropical fruits

BACHELOR'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled Active ingredients in edible coatings for tropical fruits independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague 13.4.2023

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Alena Berková

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Abstract

Mangoes are one of the most economically important tropical fruits, mainly imported to Europe or the United States. Mangoes are climacteric fruits that are perishable. Consequently, long-distance transport can result in large losses, which can result in economic losses. Edible coatings could help to prolong shelf life and maintain the quality of the fruit. When an edible coating is applied, a thin barrier is formed on the surface of the fruit for the transfer of gases, moisture, and solutes. The loss of moisture is one of the most important factors in maintaining the quality and extending the shelf life of the fruit. For this reason, this work aimed to compare the application of different natural waxes as an edible coating to prevent fruit weight loss. The comparison was made between shellac 5.5 %, shellac 10.20 % and carnauba wax. Different application methods (dipping, spraying, and spreading) were also compared. Mangoes were stored at 9 °C for 30 days. All coatings showed much lower weight loss compared to the control samples. Control samples had a weight loss of 4.21 %. The best coating that had the lowest weight loss was shellac 5.5 %. At the end of the experiment, it had a loss of 2.60 %. Carnauba wax had the highest loss (3.57 %). Regarding the method of application, the spreading had the best results with a loss of 2.56 %. However, after drying, the coating was visible on the surface. A similar result to the spreading was measured for the spraying, which showed a 0.04 % higher weight loss than the spreading. Therefore, spraying with 5.5 % shellac could serve as a suitable method of applying an edible coating to mango fruit. Based on the data, the best variant for reducing weight loss was found to be 5.5 % shellac applied by spraying.

Keywords: post-harvest losses, eco-friendly technology, *Mangifera indica*, natural waxes, shelf life

Abstrakt

Mango patří mezi ekonomicky nejvýznamnější tropické ovoce, které se dováží převážně do Evropy nebo Spojených států amerických. Mango patří mezi klimakterické ovoce, které rychle podléhá zkáze. Proto při přepravě na delší vzdálenost mohou vznikat velké ztráty, které mohou vyústit v ekonomickou ztrátu. Pro prodloužení skladovatelnosti a udržení kvality plodu by mohly napomoci jedlé povlaky. Při aplikaci jedlého povlaku se na povrchu plodu vytvoří tenká bariéra pro průchod plynů, vlhkosti a rozpuštěných látek. Ztráta vlhkosti je jedním z nejdůležitějších vlivů pro udržení kvality a prodloužení skladovatelnosti plodu. Z tohoto důvodu bylo cílem práce porovnat aplikaci různých přírodních vosků jako jedlých povlaků k zamezení ztrát hmotnosti plodů. Porovnával se šelak 5,5 %, šelak 10,20 % a karnaubský vosk. Také se porovnávaly i různé způsoby aplikace (namáčení, postřik a nátěr). Manga byla skladována v 9 °C po dobu 30 dní. Všechny povlaky prokázaly mnohem nižší ztráty hmotnosti oproti kontrolním vzorkům. Kontrolní vzorky měli ztrátu 4,21 %. Nejlepším povlakem, který měl nejmenší ztráty hmotnosti byl šelak 5,5 %. Na konci experimentu byla ztráta hmotnosti u plodů 2,60 %. Největší ztráty měl karnaubský vosk (3,57 %). Co se týče způsobu aplikace, tak zde měl nejlepší výsledky nátěr, po kterém se projevila ztráta hmotnosti 2,56 %, nicméně po uschnutí byl na povrchu viditelný povlak. Podobný výsledek jako u nátěru byl naměřen u postřiku, kde se projevila o 0,04 % vyšší ztráta hmotnosti než u nátěru. Proto by postřik šelakem 5,5 % mohl sloužit jako vhodná metoda aplikace jedlého povlaku u plodů mang. Na základě získaných dat bylo zjištěno, že nejlepší variantou pro snížení úbytku hmotnosti je 5,5 % šelak aplikovaný postřikem.

Klíčová slova: posklizňové ztráty, ekologická technologie, *Mangifera indica*, přírodní vosky, skladovatelnost

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List of the abbreviations used in the thesis

CA - controlled atmosphere storage

MAP - modified atmosphere packaging

CMC - carboxymethyl cellulose

MC - methylcellulose

HPMC - hydroxypropyl methylcellulose

HPC - hydroxypropyl cellulose

WPC - whey protein concentrates

WPI - whey protein isolates

1. Introduction

Edible coatings are not new on the market. Coatings have been used around the world for a century (Baldwin & Hagenmaier 2012). This method is expanding with the growing population and greater demand for healthy foods, including fresh fruit. It is estimated that fresh fruit production will need to increase by 70 % by 2050 (Kumar & Kalita 2017). Thanks to their antibacterial and antifungal effects, easy application, and biodegradability, edible coatings are one of the options to help extend the shelf life of fruit and reduce post-harvest losses (Armghan Khalid et al. 2022). Other benefits of edible coatings include a reduction in the use of disposable plastic packaging, which also serves to extend shelf life. The coating also contains active ingredients, for example, anti-browning agents, antimicrobial agents, colourants, and nutrition (Ju et al. 2019).

This method could help solve problems producing fresh fruit, which is post-harvest loss. These losses are caused by the natural ripening of the fruit after harvest, poor storage, manipulation, and microbial and fungal infections. Harvested fruit is also more susceptible to biotic and abiotic challenges. Biotic ones include diseases, insects, and parasites, and abiotic ones include temperature and humidity. Also, fresh fruit contains a high proportion of water by weight, which causes a shorter shelf life (Armghan Khalid et al. 2022).

2. Literature Review

2.1. Mango (*Mangifera indica*)

Mango is economically one of the most important tropical fruits in the world. In 2022, mango exports amounted to 2.1 million tonnes. The top exporting countries are Mexico, Peru, Thailand and India. The main import destinations are the United States and the European Union (FAO 2023). Mango is also called ,,King of Fruits'' because of its nutritional value, delicious taste and aroma. Mango is native to South and Southeast Asia (Singh et al. 2013). Figure 1. represents the manga extension (Warschefsky & Wettberg 2019). The first mention of mango was 4 000 years ago in Hindu literature. Today, the mango tree has spread to all tropical regions and is cultivated in many varieties (Svobodová 2011).

Mango is a perennial, evergreen tree from the family *Anacardiaceae,* genus *Mangifera*. Usually grows 3-10 m but can grow up to 30 m (Bally 2006). The leaves can be up to 30 cm long (Svobodová 2011). They are alternate, entire, petiolate and dark green. Young leaves are red (Fig. 2). Cut twigs secrete latex. The inflorescence is a branched panicle (Fig. 3). Flowers are partly bisexual and partly male (Bally 2006). The individual flowers are five-petalled, yellowish red (Fig. 3). The diameter of the flower is 6 mm (Svobodová 2011). The trees flower irregularly. Some trees may not flower for 10 to 20 years or more. The entire inflorescence produces 1-5 fruits. The fruits are located on a long stalk and are 10-15 cm long (Bally 2006). Contain high amounts of vitamin A, C, K, β-carotenes, antioxidants and fibre (Svobodová 2011). The fruit is classified as a drupe. Maturation of the fruit from fertilisation is between 2-5 months depending on the variety and temperature. The skin of the mango is waxy. The flesh is sweet, yellow to orange. Inside the fruit, there is a seed in a leathery endocarp (Bally 2006). During the ripening of the mango, may biochemical changes occur in the fruit. The process involves increased respiration, alteration of structural polysaccharides resulting in softening of the fruit, degradation of chlorophyll and formation of carotenoids and hydrolysis of starch to simple sugar (Lalel et al. 2003). The mango trees also have many uses. The main product of the tree is the fruit. It is consumed either fresh or processed as juice, chutneys, achars, essences, wines etc. (Bally 2006). Other uses include the leaves as food (Bally 2006) or for extraction of xanthon mangiferin (Svobodová 2011). Different parts of trees are used in Ayurvedic medicine and other traditional medicine (Govindan 2019). Mango has a positive effect on digestion, lower blood pressure, increases immunity, is beneficial in the treatment of asthma, and has anti-inflammatory effects (Svobodová 2011).

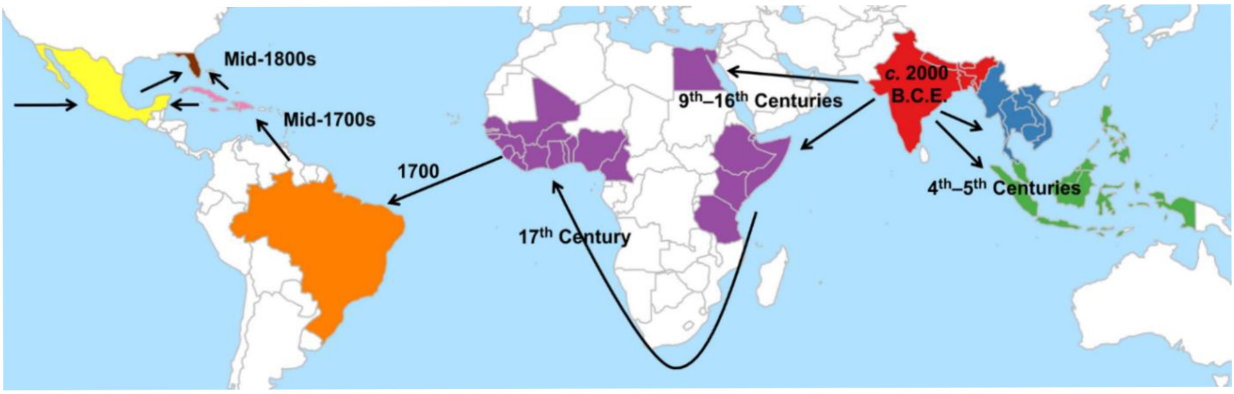

Figure 1. Expansion of the mango tree over time. Source: (Warschefsky & Wettberg 2019)

Figure 2. New leaf growth (a), picture of *Mangifer indica* tree (b). Source: (Bally 2006)

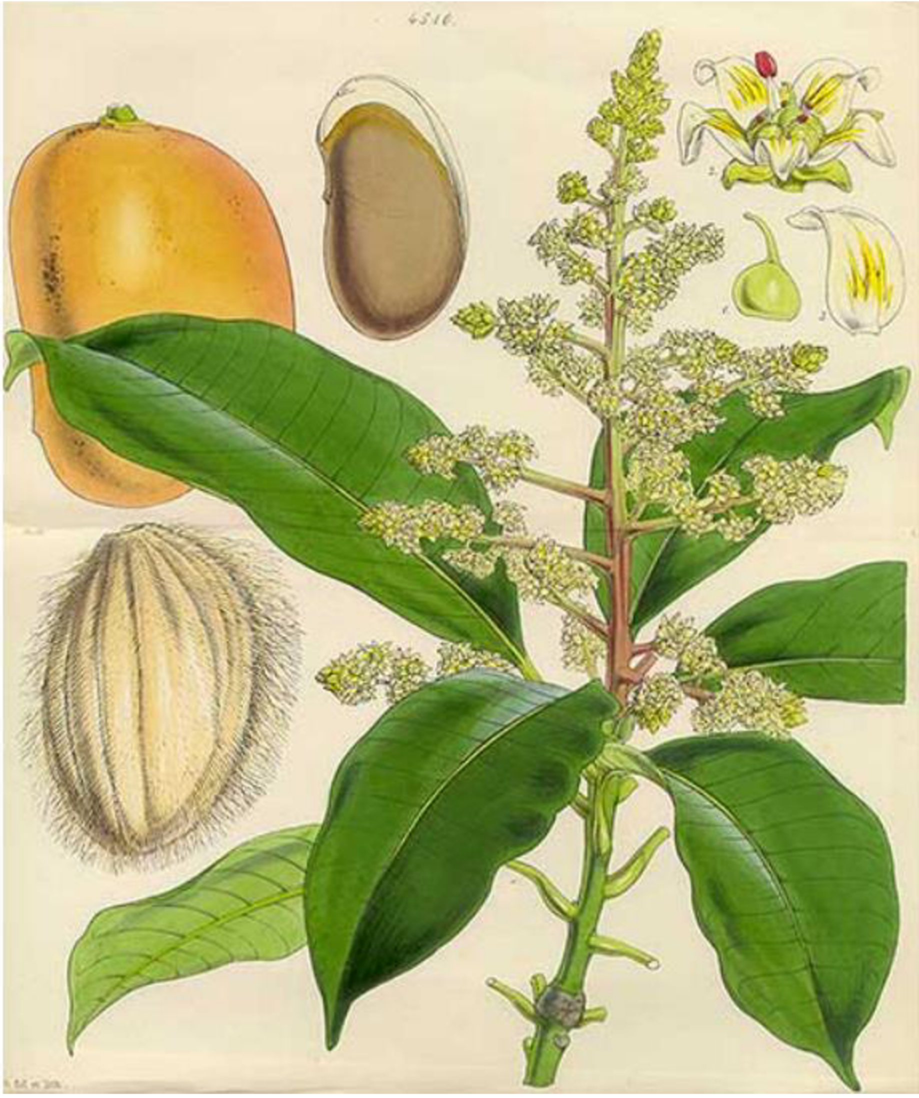

Figure 3. Picture of inflorescence, flower, fruit, and seed of *Mangifera indica.* Source: (Hooker & Smith 1850)

2.2. Post-harvest handling of mango

Post-harvest losses occur at various stages of fruit processing. Losses due to bruising, damage, and weight loss are caused by poor harvesting, handling, poor packaging, and transport conditions. Losses due to rot can be attributed to improper disease protection during production or improper handling after harvest (Sharma et al. 2019).

The first major losses occur during the harvest itself. Strict rules must be followed during harvesting, which is not always the case and can lead to large losses. The mangoes are harvested manually using harvesting equipment. To avoid contamination, all tools must be disinfected and cleaned. The harvesting basket must be lined with paper or bags to avoid damage to the fruit by sharp objects. The harvested mangoes should not come into contact with the ground, where microbial contamination could occur. They should also not be exposed to sunlight, as this would lead to heat accumulation. As a final precaution, a 5 cm stem should be kept to avoid latex damage to the fruit. The fruit needs to be handled carefully to minimise damage (Mohammed & Craig 2018).

Harvesting is followed by trimming and delatexing. During these processes, the stalk is removed, and the fresh latex is subsequently removed from the fruit. One method of delatexing is to let the latex drip for 30 minutes. The second method is to dip the place where the freshly cut stem was in a 1 % alum solution. Then the mangoes are sorted according to quality. The fruit must be ripe, well-formed, clean, and free from insect damage, diseases, and mechanical damage.

Hot water treatment is conducted after harvesting to prevent the spread of diseases. Hot water treatment is one of the most effective treatments against rot. It is a treatment against anthracnose and stem-end rot. In this treatment, the ripe green fruits are immersed in hot water at a temperature of 52 to 55 °C for 5 to 10 minutes. If the temperature drops, the effectiveness decreases. On the other hand, if the temperature rises above 55 °C, the skin is burnt. Only in the range of 52-55 °C is the disease killed without damaging the fruit. For maximum effect in controlling fruit diseases, treatments should be carried out within 36 hours of harvesting. The final stage is packing and transport. During these stages, care must be taken to ensure that the mango arrives undamaged and in good condition (FAO 2018).

2.3. Factors affecting the safety and quality of mango

The mango is a perishable fruit. Under the right conditions, its shelf life can be extended. Factors that can extend shelf life include temperature, humidity and gas composition during storage and transport. The time of harvest is also particularly important. If harvested at an unripe stage of development, the quality and taste of the ripe fruit will deteriorate. In the case of unripe and overripe fruit, good storage and transport conditions are insufficient, and losses may occur (Yanik Kocak et al. 2019).

2.3.1. Gas composition

The composition of the gases in the atmosphere, such as oxygen, carbon dioxide or ethylene, has a considerable impact on the respiration rate and the extension of the shelf-life. Mangoes are climacteric fruits. This means that during ripening there is increased respiration and higher ethylene production. Ethylene regulates the ripening process. When the fruit is unripe, ethanol production is extremely low, but even a low concentration (0.01 ppm) can still trigger the ripening process. Exogenous treatment of mangoes with ethylene increases autocatalytic production and thus accelerates ripening (Gamage & Rahman 1999).

Oxygen is another gas that affects the ripening of the fruit. Oxygen slows the growth of anaerobic microorganisms but accelerates the growth of aerobic microorganisms. It also accelerates fruit ripening and senescence and promotes discolouration and spoilage due to the growth of microorganisms. Despite its negative effects, its presence in low concentration is necessary to maintain the basic process of aerobic respiration in fruits (Floros & Matsos 2005). Normally 21 % of oxygen is found in the atmosphere. During storage, the amount of oxygen in the atmosphere is between 2-6 % (Singh et al. 2013). The last-mentioned gas is carbon dioxide. Carbon dioxide inhibits the growth and multiplication of microorganisms and slows down the rate of respiration. It is soluble in both water and lipids. Its solubility increases with decreasing temperature. The dissolution of carbon dioxide can cause the collapse of the packing (Floros & Matsos 2005).

The composition of oxygen and carbon dioxide can be affected by the storage of the fruit. Mangoes are stored either in a controlled atmosphere (CA) or modified atmosphere packaging (MAP). In CA storage, the product is stored in an airtight room where the gas composition of the room is maintained (Gamage & Rahman 1999). CA storage reduces the oxygen concentration and increases the carbon dioxide concentration. Nitrogen can be added to this concentration. The amount of oxygen and carbon dioxide during storage varies according to the variety of mango (Singh et al. 2013). According to Paull & Chen (2014) and Singh et al. (2013), the amount of oxygen is around 3-6 % and the amount of carbon dioxide is around 5-10 %. The entire storage process is carried out at a temperature of around 10-13 °C and relative humidity of around 85-90 % (Paull & Chen 2014). Higher humidity at lower temperature prevents condensation of water on the surface and prevent excessive drying. At the same time, it minimizes decay (Ben-Yehoshua et al. 2005). CA reduces the respiration rate, ethanol production, delayed skin colouration, and the softening and ripening process of the fruit (Lalel et al. 2005). The disadvantage of CA storage is the high cost of establishment, maintenance, and operation (Singh et al. 2013). The second storage method is MAP. MAP uses a permeable polymer film to modify the atmosphere around the fruit during storage (Yahia 1998). During storage, the oxygen content is reduced, and the carbon dioxide concentration is increased. In the case of mangoes, the amount of oxygen is around 5 % as well as carbon dioxide and the temperature should be around 10-15 °C. This type of storage slows down the ripening process, ethylene production reduces softening (Floros & Matsos 2005) and prevents water loss (Miller et al. 1983). The higher carbon dioxide content reduces the growth of microbes. This method has a disadvantage. During storage, oxygen can be excluded, and anaerobic respiration can occur. This leads to odours, discolouration, and softness of the tissue. It is also a method that requires special, expensive equipment and specially trained personnel. This method of storage produces a large volume of packaging. This results in increased transportation and retail requirements. A final disadvantage is that once the consumer opens the package all the benefits of MAP are lost (Floros & Matsos 2005).

2.3.2. Temperature

Temperature, along with humidity is the most important factor in prolonging shelf life. The mangoes are ripened at a temperature of 20-23 °C. The temperature for storing and transporting mangoes is around 8-13 °C depending on the cultivar (Hussen 2021). If the temperature is not maintained, the fruit can be damaged, leading to a deterioration of sensory properties or a reduction in nutritional value. This results in reduced fruit quality and shelf life. The storage temperature also depends on the maturity of the fruit. Pre-climacteric fruits are more sensitive to chilling injury than post-climacteric fruits (Singh et al. 2013). The overall shelf life of unripe fruit is longer than that of fruit harvested at an advanced stage of physiological ripeness.

The most effective technique for extending shelf life and ensuring quality is low-temperature storage (Medlicott et al. 1990). Low temperature inhibits the ripening process and slows or stops the growth and reproduction of microorganisms that cause various diseases. It also prevents the growth of decaying organisms (Ahmad & Siddiqui 2015). The optimum temperature for storing mangoes is 12 °C (Medlicott et al. 1990). At lower temperatures, the fruit is at risk of chilling injury. Damage symptoms may not appear until the fruit has moved to a higher temperature. Chilling injury causes internal discolouration, external discolouration, pitting of surface or skin, uneven ripening, lack of flavour development, increased development of surface mould and rot, reduction of nutritional value and increased susceptibility to fungal attack. The extent of damage is affected by temperature and humidity, ethylene content, the sensitivity of the product to low temperatures and exposure time to a given temperature (Gamage & Rahman 1999).

Temperature management is also used in post-harvest treatment. It is a high-temperature treatment/sanitisation of the fruit. Pests and diseases are sanitised and eliminated during this process. Fruit flies, in particular, are eliminated. In heat disinfection, the fruit is heated to the required temperature for a certain period. There are several methods of disinfection (tab. 1). Vapour heat treatment is the first technique. Through this process, air that is nearly saturated with moisture is heated and passes through the fruit. During the process, the air's moisture condenses on the fruit's surface (Jacobi et al. 2001). The fruit is heated to 46.5 °C for 10 minutes (Jacobi & Wong 1992). The temperature and application time may vary based on each country's requirements. Heating with forced hot air is the second technique. This technique is not used for mangoes. In this method, the fruit is heated by passing air of a certain temperature over the fruit bed. If the humidity is significantly reduced during the process, weight loss and drying may occur. Forced hot air treatment does not condense on the surface of the fruit, which is different from vapour heat treatment (Jacobi et al. 2001).

Table 1. Post-harvest disinfection methods for mangoes.

Application	Temperature	Time	References
Vapor heat treatment	46.5°C	40 min	Jacobi 1992
	47°C	40 min	Lestari 2017
	47°C	25 min	Shah 2021
Forced hot-air heating	47.2°C	20 min	Yahia 2011
	47°C	15 min	Heather 1997
	48°C	150 min	Raymond 1991
	51.5°C	125 min	Miller 1991
	47°C	20 min	Hoa 2010
Hot water immersion treatnent	55°C	3 min	Jacobi 1992
	46.1°C	110 min	Shellie 2002
	45.9-46.3°C	90 min	Nascimento 1992
	46.4-47°C	95 min	Hernández 2012

2.3.3. Humidity

Mango contains a large amount of water 83.3 %, which is slowly lost through respiration (Alam & Shima Bibi 2020). According to Elhefny et al. (2012), after 8 weeks in CA storage, 2.35-2.85 % of water is lost through respiration. If mangoes are stored in the air, 9.18 % of water is lost through respiration. For this reason, it is important to maintain relative humidity in the storage area. Otherwise, there will be a loss of weight, and deterioration in appearance, texture, and flavour (Ahmad & Siddiqui 2015). On the contrary, if the humidity is high, microorganisms develop, and diseases spread. This reduces market value and shortens shelf life. The fruit must also not be exposed to the sun, which would cause high evaporation of water (Yanik Kocak et al. 2019). The ratio of transpiration is influenced by surface texture and conditions, relative humidity, storage temperature, air movement and circulation, atmospheric pressure, post-harvest cooling rate and the ratio of surface to volume of the fruit (Gamage & Rahman 1999). Relative humidity should be between 90-95 % to avoid water loss and drying out (Hussen 2021).

2.3.4. Diseases and pests

The fruit of mango is very vulnerable to attack by insects or rotting organisms. Postharvest losses are primarily caused by interaction between fresh fruit and contaminated microbes through water, soil, injure fruit and postharvest industrial processes (FAO 2018). Most losses in mangoes are the result of rotting.

The most well-known diseases include anthracnose (*Colletotrichum gloeosporioides*) and stem-end rot (*Diplodi natalensis*). Anthracnose is most common in areas with high temperatures and humidity. Infection can be on fruit, leaves, flowers, and twigs. It remains latent in most fruits and does not begin to show symptoms until the ripening stage. During infection, sunken, dark brown to black spots are found on the fruit (Nelson 2008). The second most common disease is stem-end rot (*Diplodi natalensis*). The disease most often affects the stem end but can also affect any other part of the fruit. Infection can be reduced if 1-2 cm of the stem is left at harvest. Tab. 2 presents other mango diseases and their pathogens. There are several options for disease prevention, for example, hot water treatment and vapour heat treatment or fungicides (Yahia 1999).

It is not only diseases that cause significant losses in production. Pests can also cause major losses by feeding, scratching, or laying eggs in the pulp or seeds. The most abundant pests are fruit flies, weevils, and butterfly larvae. These agents enter the flesh where they subsequently cause damage. Pesticides are the most common pest control. For harvested fruit, high-temperature disinfection (vapour heat treatment) and low-temperature can be used as pest control. The problem with protection is the increasing resistance of pests to chemicals (Peña et al. 1998; Yahia 1999).

Table 2. Diseases of mango.

Diseases	**Causal organisms (pathogens)**	**References**
Anthracnose	*Colletotrichum gloeosporioides, C. acutatum*	(Nelson 2008; Ploetz 2003)
Stem-end rot	*Neofusicoccum sp., Lasiodiplodia theobromae* (syn. *Diplodia natalensis*), *Diaporthe pseudophoenicicola, Dothiorella dominicana, Phomopsis mangiferae, Pestalotiopsis mangiferae,Cytosphaera mangiferae*	(Hara et al. 2016; Johnson et al. 1990; Coates et al. 1997; Ploetz 2003)
Powdery mildew	*Erysiphe quercicola, Oidium mangiferae*	(Feygenberg et al. 2021; Parida et al. 2019)
Scab mold (mango scab)	*Elsinoë mangiferae* (syn. *Denticularia maniferae*), *Cannodium mangifera*	(Alcorn et al. 1999; Yahia 1999)
Black mold rot	*Aspergillus niger*	(Yahia 1999)
Alternaria rot (black spot)	*Alternaria alternata*	(Ploetz 2003, Yahia 1999)
Bacterial black spot (black canker)	*Xanthomonas campestris* pv. *Mangiferaeindicae*	(Ploetz 2003)
Sooty moulds and black mildew	*Cannodium mangifera, Meliola mangiferae*	(Yahia 1999; Parida et al. 2019; Ploetz 2003)

2.4. Edible coatings

As the amount of post-harvest losses increases, it is important to use methods that maintain quality and extend shelf life, thus reducing the amount of post-harvest losses. The edible coating could solve this problem. This method is used to extend shelf life and maintain food quality.

An edible coating is a thin layer of edible material formed on the surface of food (Smith et al. 1987; Mchugh & Senesi 2000). The thickness should be less than 0.3 mm (Olivas & Barbosa-Cánovas 2009). The layer is composed of biopolymers and other additives. It acts as a supplement or replacement for the natural protective wax coating.

It creates a barrier to the movement of moisture, gases, and solutes in the food. Figure 4. shows the main properties/functions of edible coatings. The coating is applied to the surface by dipping, spraying, or brushing (Smith et al. 1987; Nisperos-Carriedo et al. 1991; Mchugh & Senesi 2000). The effectiveness of the coating depends to a large extent on the temperature, alkalinity, thickness, type of coating and the variety and condition of the fruit (Dhall 2013). Coatings, in the right combination with additives, offer many good properties such as UV protection, substance transfer between the barrier and food, bioactive ingredients and antimicrobial effect. The coatings are made from natural substances and are therefore biodegradable and non-pollution (Díaz-Montes & Castro-Muñoz 2021). By being made from natural ingredients, the coatings could replace conventional disposable plastic and another packaging that burden the environment. Coatings also have disadvantages. One of them is that a bad combination of ingredients can reduce the quality of the product. For example, the formation of undesirable flavour (Quirós-Sauceda et al. 2014).

Coatings are part of the food and therefore require neutral sensory properties (Guilbert et al. 1997). For commercial use, the coating must meet many safety and performance requirements. It must not shrink, separate, or deteriorate during storage and must be odourless and tasteless. During application and storage, it must not crack, discolour, or peel. The packaging must allow or restrict the passage of gases, water vapour and other substances (Baldwin & Hagenmaier 2012).

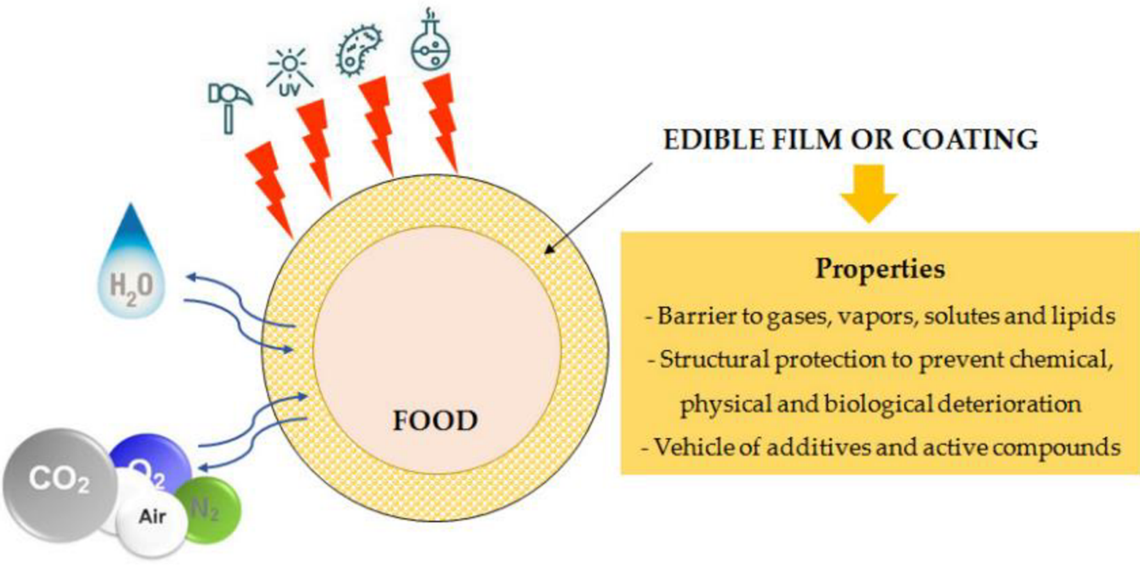

Figure 4. Main properties of edible coatings. Source: (Valdés et al. 2017).

2.4.1. History of edible coatings

The first mention of the use of edible coatings was in the 12th and 13th centuries. It was an experiment conducted by the Chinese. In this experiment, they used melted wax which they applied to lemons and oranges. They found that using wax reduces water loss and extends shelf life. With satisfactory results, they started experimenting with other fruits (Hardenburg 1967). In 1916, A. F. Hofman patented a method of fruit preservation in which he used melted wax to preserve the fruit. The fruit was first cooled, sterilised by ultraviolet radiation, and then melted wax was applied (Hofman 1916).

The largest scale of application occurred in the 20th century. The first commercially available edible coatings were hot-melt paraffin waxes for fruit from the 1930s (Park 1999; Dhall 2013). Thirty years later, edible coatings still had little commercial experience and only waxed coatings were used. Over the next few years, there was a huge expansion of this method. There was a proliferation of other preservation methods such as refrigeration, controlled atmosphere storage, UV, and gamma radiation to keep food safe. Nowadays, there is a great expansion and exploration of edible coating not only for preserving fruit and vegetable but also for other products (Olivas & Barbosa-Cánovas 2009). According to data from Mordor Intelligence (2020), the global edible coatings market for fruit and vegetables is valued at USD 709.77 million in 2020. It is expected to grow at a CAGR of 6.76 % during the period 2021-2026.

2.4.2. Legislation of edible coatings

Since the edible coating is part of the edible portion of the food, it must meet all legal requirements. The regulation that the coating must comply with may vary from country to country (Armghan Khalid et al. 2022). Edible coatings are those that are categorized as food products, food additives, food components, food contact substances or food packaging materials, according to European Directive (95/2/EC) (Ncama et al. 2018; Cloete et al. 2022).

All additives must be accepted and listed in the EU positive list together with their usage guidelines, according to European law. All ingredients must adhere to safety standards, satisfy technological criteria, and not deceive consumers. The requirement for additives is outlined in EC Regulation 1333/2008. Definitions for use, labelling and procedures are given. Some of the ingredients that are allowed include beeswax (E901), carnauba wax (E903), pectin (E440), shellac (E904), xanthan gum (E415) and others (European Parliament 2008). All ingredients that come into contact with the food shall comply with good manufacturing practices, shall not alter the colour, taste, odour or texture of the food and the material shall not adversely affect the food or endanger human healthy (Armghan Khalid et al. 2022).

2.4.3. Edible coating forming methods

Edible coatings are mostly made from materials that can form films. These materials include hydrocolloids as polysaccharides and proteins (Saha & Bhattacharya 2010) and lipids (Guilbert et al. 1997). The coating can consist of either a single layer or multiple layers of different substances. These substances must be able to dissolve in solvents such as ethanol, water or a mixture of water and alcohol (Bourtoom 2008). The casting method or wet method is used to form the coating. It can also be referred to as solvent casting (Peressini et al. 2003). In this method, the biopolymers are dissolved or dispersed in a liquid phase and then applied to the surface (Guilbert et al. 1997). The lipid-based coatings are melted and solidified (Hauzoukim et al. 2020). During heating, substances can be added to the solution to help improve the quality of the coating. These substances include plasticisers, emulsifiers, antimicrobials, and others. To obtain high-quality coatings they must be synthesised and dried under specific temperature and humidity conditions. It is possible to adjust the pH or heat the solution to improve the dispersion of a particular polymer (Guilbert et al. 1996).

When properly used and combined, this method allows for structural strengthening, reduction of particle clumping, and improved visual and tactile properties on the product surface (Guilbert et al. 1997). Good coating cohesion depends on the structure, temperature, a solvent used or additives such as plasticisers and emulsifiers (Tharanathan 2003).

2.4.4. Types of edible coatings

Types of edible coating can be divided into three main groups. These groups are divided according to the main ingredient of which they are composed (Hassan et al.2018; Armghan Khalid et al. 2022). The complete grouping, including the individual substances belonging to each group, is shown in figure 5.

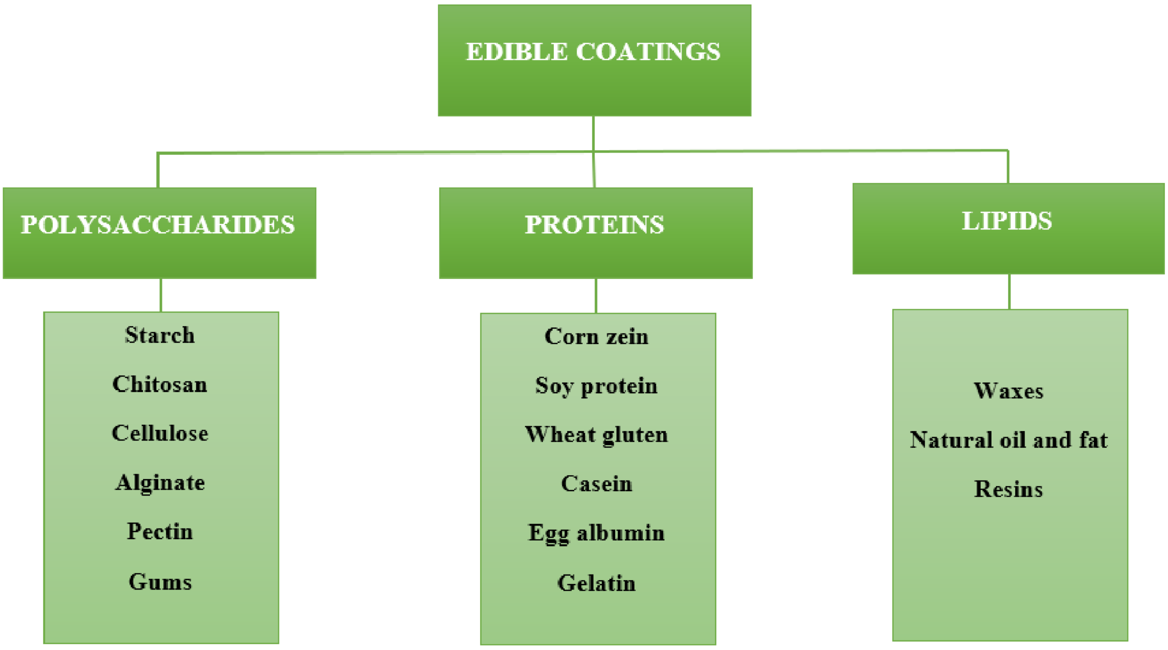

Figure 5. Ingredients in edible coatings. Source: Author

Polysaccharides-based edible coating

Polysaccharides are a type of polymer found in nature. Most available polymers are extracted from plants or animals. The disadvantage of some polysaccharide-based coatings is the thin moisture barrier caused by the hydrophilic nature of polysaccharides (Dhall 2013; Ju et al. 2019). Instead of creating a moisture barrier, hydrophilic coatings sometimes act as a sacrificial agent. This implies that they can form a relatively thick layer on the surface of the food and deliberately absorb water and lose it first, providing temporary moisture protection for the food (Baldwin et al. 1995; Orts & Pavlath 2009). Although polysaccharide coatings can have drawbacks, they also offer many qualities. One of these is a good barrier property for gases, especially the low oxygen permeability of starch, which reduces the respiration rate of fresh fruit. Another advantage is good availability (Fakhouri et al. 2015).

Starch

Starch is a natural polymer. It is a storage polysaccharide of plants. It is stored in the form of starch grains. It is mostly obtained from cereals, legumes, and tubers. Starch has high potential in the production of edible coatings to extend the shelf life. It is easily available, low cost, renewable, tasteless, easy to process, colourless, non-toxic, and biodegradable (Nešić et al. 2019). Starch consists of two glucose polymerases amylose and amylopectin. Amylose is a linear polymer and amylopectin is a highly branched polymer. The ratio of amylose and amylopectin is very important for the properties of coatings (Cano et al. 2014; Nešić et al. 2019). According to Cano et al. (2014), higher amylose content produces stiffer, more durable, less stretchable coatings with lower oxygen permeability but greater water-binding capacity. To enhance the proprieties, it is possible to add other components to the starch such as plasticisers to increase flexibility and processibility (Quezada-Gallo 2009) or essential oils, and plant extracts to improve biological properties (Sharma et al. 2021).

Chitosan

Chitosan is a natural polysaccharide. It is obtained from chitin by deacetylation in an alkaline condition. After cellulose, chitin is the second most prevalent biopolymer. Chitosan is found in the exoskeleton of crustaceans, in the cell walls of fungi and in other biological materials. Its potential for forming edible coatings is due to its antibacterial, antifungal effects, biodegradability, and film-forming properties (Lacroix & le Tien 2005; Elsabee & Abdou 2013). Chitosan is selectively permeable to gases, namely oxygen and carbon dioxide, which helps to prolong shelf life (Zhu et al. 2008). The only disadvantage is the high-water vapour permeability (Suyatma et al. 2004).

As with starch, additional components can be added to the coating to improve properties and extend shelf life. For example, according to Vieira et al. (2016), the combination of chitosan and *Aloe vera* positively reduced mould contamination after harvest and reduced the water loss rate. Packaging with a 0.5 % liquid fraction of chitosan and *A. vera* had the best results. There was an extension of shelf life of approximately 5 days. The combination of chitosan-based coating and glycerol is also successful. This combination has been used to extend the shelf life of strawberries. Due to the presence of glycerol, the coating showed a hydrophobic character. The coating displayed excellent bactericidal and fungicidal properties for one week. During the entire, period there was no change in texture, taste, or aroma (Pavinatto et al. 2020).

Cellulose

Cellulose is contained in all terrestrial plants on Earth. It is found in cell walls, where it functions as the main building material for primary cell walls. Together with lignin and hemicellulose, they participate in the formation of secondary walls. It is the most abundant biopolymer on Earth. Cellulose forms strong crystalline microfibres that are insoluble in water and most organic solvents. It is a very cheap but insoluble raw material (Lacroix & le Tien 2005; Dhall 2013). To increase the solubility of cellulose it is possible to increase the action of alkali. During the process, the structure swells and subsequent reaction with chloroacetic acid, methyl chloride or propylene oxide produces carboxymethyl cellulose (CMC), methylcellulose (MC), hydroxypropyl methylcellulose (HPMC) or hydroxypropyl cellulose (HPC). Cellulose derivates are colourless, tasteless, odourless, transparent, and resistant to damage, water-soluble, moderately permeable to moisture and oxygen and have good film-forming properties (Bourtoom 2008; Dhall 2013). HPCM and MC are effective derivatives for reducing oil absorption. For this reason, they are suitable for reducing absorption in fried products. According to García et al. (2002), MC is more effective in reducing than HPMC. MC has also proven to be a beneficial coating for avocados. The application of this coating slowed down ripening and improved physiological properties. Respiration was slowed, the discolouration of the skin and flesh was reduced, tissue softening was reduced, and the overall shelf life was extended from 6 to 10 days (Maftoonazad & Ramaswamy 2005).

Alginate

Alginate is obtained from brown algae from the family *Phaeophyceae*. Alginates consist of β-D-mannuronic acid (C) and α-L-guluronic acid (G) in different ratios, arrangements, and molecular weights. In the presence of divalent or multivalent cations, alginate gels form crosslinked structures and thus become insoluble (Nešić et al. 2019). It is a hydrophilic colloidal carbohydrate. It has excellent colloidal properties which include thickening, stabilisation, suspension, film forming, gel production and emulsion stabilisation (Rhim 2004). Alginate coatings can slow down weight loss, softening, acidity, discolouration (Valero et al. 2013) and flavour (Armghan Khalid et al. 2022). Additives and antibacterial agents may be added to increase the effectiveness of the coating. According to Azarakhsh et al. (2014), the addition of 0.3 % (w/v) lemongrass to the alginate coating reduces the respiration rate, weight loss, and the number of yeasts and moulds in the sliced pineapple. The fruit will retain its sensory and morphological characteristics.

Pectin

Pectin is a class of complex polysaccharides found in plants. It is obtained from cell walls and middle lamellae of plants, most commonly from citrus fruits or apples, as a by-product of extraction (Olivas & Barbosa-Cánovas 2009). It is consisting of β-1,4-linked d-galacturonic acid residues. Uronic carboxylic acids are either fully or partially methyl-esterified (Thakur et al. 1997). Highly methyl-esterified pectin (high-methoxy pectin) contains more than 50 % galacturonic acid residues and forms excellent coatings. Gels are formed by hydrophobic interactions in aqueous and acidic conditions and at high sugar content. Partially methyl-esterified pectin (low-methoxy pectin) contains less than 50 % galacturonic acid residues and can also be used to make coatings. Low methoxy pectin is obtained by controlled de-esterification (pH, temperature, and time controlled) and gels are formed when calcium ions are present (Lacroix & le Tien 2005; Valdés et al. 2015).

Pectin is used in food mainly for its gelling properties (Olivas & Barbosa-Cánovas 2009) or as an emulsifier, stabiliser, and thickener (Thakur et al. 1997). According to Moalemyian et al. (2012), pectin coating reduces the amount of evaporated water, decreases the rate of respiration, imparts gloss, and thus improves the appearance of the fruit. It also reduced rotting, softening of the tissue and colour changes in the skin and flesh of the fruit. The coating was applied to mangoes whose storage time at room temperature was extended from 7 to 13 days. This means that the storage time has doubled. This coating may have one drawback and that is anaerobic respiration.

Gums

The gums are of plant origin and are dissolved in water. They are formed on the surface of the plant by the drying of plant juices (pith) which are exuded from the plant due to stress or injury. From a chemical point of view, gums are complex carbohydrates of high molar mass with colloidal properties. They can be composed of galactose, arabinose, rhamnose, xylose, galacturonic acid, as well as others (Aires da Silva et al. 2021). It has a wide range of applications due to its ability to form a gel or viscous solution or due to its stabilising, emulsion, and thickening properties. It is mainly used in the food and pharmaceutical industries (Mano et al. 2007; Prajapati et al. 2013). Gums form a coating with specific qualities of plasticity, tensile strength (Barak & Mudgil 2014), transparency, and solubility when it is applied to the surface (Dick et al. 2015). In addition to its good properties and qualities, it is also a cheap, accessible, and non-toxic material (Prajapati et al. 2013).

The most used gums include guar gum, gum arabic/acacia gum, xanthan gum, peach gum and others. Guar gum is extracted from the endosperm of the seeds of the *Cyamopsis tetragonoloba* bush. Guar gum can decrease and slow the change in total soluble solids and lessen weight loss. It is also used because of its low cost, availability, and degradability (Ebrahimi & Rastegar 2020). Gum Arabic is extracted from the stems and branches of the *Acacia arabica*. It is used for its emulsifying, film-forming, and encapsulating properties (Motlagh et al. 2006). According to Ali et al. (2010), the coating significantly delayed changes in weight, firmness, titratable acidity, solute concentration, and colour, thereby allowing quality to be maintained during storage. Xanthan gum is secreted by the microorganism *Xanthomonas campestris*. It is soluble in cold water and solutions. It creates a highly viscous solution that is resistant to enzymatic deterioration and more stable over a wide range of pH, and temperature. It serves as a stabiliser, emulsifier and thickener (Sworn 2009).

Protein-based edible coating

The protein-based edible coating can be divided into groups based on native states of fibrous and globular proteins. Animal tissues give rise to water-insoluble proteins known as fibrous proteins. Casein, whey protein, egg albumin and gelatin belong to the members of this category. Globular proteins are derived from plants and are water-soluble. Corn zein, wheat gluten, and soy protein are included in this group. Protein coatings are formed from solutions or dispersions of proteins when the solvent evaporates. This process produces the extensive structure required for coating formation. The resulting coating becomes less elastic and less permeable to gases, vapors and liquids but more durable (Bourtoom 2008; Dhall 2013). However, protein coatings, are hydrophilic in nature. This property makes them a poor barrier to water vapour. On the other hand, they provide a good barrier to oxygen at low and medium relative humidity. The properties of coatings can be improved by chemical or enzymatic methods. To increase water vapour resistance, a good combination is with lipids, which have excellent barrier properties (Bourtoom 2009).

Corn zein

Zein is a natural protein obtained from maise. It has a high proportion of non-polar amino acids and a low proportion of basic and acidic amino acids. As a result, it is not soluble in water but only in ethanol. Zein produces a strong, glossy, hydrophobic, grease- and micro-resistance coating. In addition, it is quite flexible, compressible (Shukla & Cheryan 2001), forms an excellent barrier to gases (Arcan & Yemenicioğlu 2011) and has reduced moisture permeability compared to other protein coatings (Moradi et al. 2016). Although it has many excellent properties, the coating formed is brittle and so plasticisers must be added (Lawton 2004). Scramin et al. (2011) confirmed the brittleness of zein coatings without the use of a plasticiser. Also, found that the loss of fresh substance is lower when the pear is coated with zein. According to Bai et al. (2003), zein coating could replace shellac coating or carnauba wax. The coating maintained a quality similar to commercial shellac coating and extended shelf life over carnauba wax.

Soy protein

Soy protein is obtained by isolation from soybeans. The protein consists of a mixture of albumin and globulin. Approximately 90 % is created by the globular structure. Subsequently, it is divided into fractions according to molecular weight and sedimentation coefficient. In the process of extracting soy oil, soy protein is produced as a by-product (soybean flour). The soybean flour is further purified to obtain a protein concentrate or isolate, which is used to form a coating (Guerrero et al. 2010). Soy isolate is an available, inexpensive, biodegradable, and nutritious material (Cao et al. 2007). However, it has attracted the most attention due to its low oxygen permeability. It has a lower permeability than low-density polyethene, starch or methylcellulose (Ou et al. 2004). However, it also has the disadvantage of forming brittle coatings when the plasticiser content is low. Conversely, it forms sticky coatings when the plasticiser content is high (Guerrero et al. 2010). Negative properties of the coating include an undesirable beany taste (Sabato et al. 2001). These problems can be solved by combining them with other materials such as chitosan (Zhang et al. 2018), gelatin, alginate (Cao et al. 2007), whey protein (Sabato et al. 2001), etc. For example, weight loss and softening rate were reduced, loss of strength was prevented, and the textural properties of the tissues were improved when combined with chitosan (Zhang et al. 2018). In combination with alginate, moisture loss was reduced, and total solids content was maintained (Ahmed & Sadiq Butt 2014).

Wheat gluten

Wheat gluten is a storage protein in wheat. Gluten is a tough mass obtained by leaching starch and removing water-soluble substances from wheat flour dough. Gluten is 75-85 % of wheat proteins. These proteins are divided into two groups: gliadin and glutenin. They are divided according to their solubility in alcohol. Both groups influence the rheological properties, and their ratio is important to obtain the right quality of the final product. Gluten helps to maintain moisture and texture (Wieser 2007). Gluten is associated with various diseases, e.g., allergies, coeliac disease and presumed non-coeliac gluten sensitivity. This may have a detrimental effect on the use of gluten-based coating (Biesiekierski 2017).

Whey gluten-based coating is mainly used due to its good oxygen barrier (Gennadios et al. 1993). The coatings help to reduce weight loss and maintain visual quality and taste during storage (Tanada-Palmu & Grosso 2005). However, it also has it is negative such as low mechanical strength and poor water resistance (Xu & Li 2023). Based on (Tanada-Palmu et al. 2000) study, adding a plasticiser such as glycerol will reduce water vapour permeability, oxygen, elongation at break and increase tensile strength. Alternatively, the addition of lipids to the coating will also reduce the water vapour permeability (Gennadios et al. 1993; Tanada-Palmu & Grosso 2005).

Whey protein

Whey protein is found in milk, where it makes up 20 % of the protein. The remaining 80 % of the protein is made up of casein. Whey protein is obtained as a by-product of cheese production. Depending on the protein concentration, it is divided into whey protein concentrates (WPC) and whey protein isolates (WPI). WPC has a higher lactose content and is present in different concentrations from 35 to 80 %. WPI is the purest form of whey protein. It contains at least 90 % protein and almost no fat or lactose (Gangurde et al. 2011). Both WPI and WPC are used to form a coating.

Whey coatings have good coating properties and produce a tough, flexible, and transparent coating. Moreover, the coating also effectively minimises enzymatic browning (Perez-Gago et al. 2005). Whey protein isolate-based coating makes an effective gas barrier, claim Cisneros-Zevallos & Krochta (2003). However, the relative humidity of the atmosphere and the thickness of the coating affect the permeability of this barrier. It follows that as the humidity decreases, the gas barrier becomes thicker. When the relative humidity is low, the oxygen content decreases and anaerobic respiration occurs, an undesirable process that affects the quality of the fruit. In combination with other ingredients such as rice bran oil, the increase in acidity is slowed, weight loss is reduced and the soluble solid, firmness, colour and overall sensory properties are maintained (Hassani et al. 2012). Like wheat gluten, it also has a poor moisture barrier. This can be remedied by combining it with lipids (Perez-Gago et al. 2005).

Casein

Casein is contained in milk. It makes up the majority of the protein in milk. It is divided into groups according to calcium sensitivity. αs1-casein, αs2-casein and β–casein is calcium sensitive and κ–casein is calcium insensitive. K-casein is found mainly on the surface of the micelles. It stabilises the caseins that are sensitive to calcium. Together they form casein micelles in milk. Each protein component influences the formation of casein coatings by its properties (Horne 2006). Precipitation of casein from milk at pH 4.6 and dissolution in alkali yields commercially available caseinate. If NaOH is used to adjust the pH, sodium caseinate is formed. If CaOH is used, calcium caseinate is formed. These are the most common forms of caseinates used (Fabra et al. 2010).

Casein forms coatings without further processing due to a large amount of electrostatic, hydrophobic, and intermolecular hydrogen bonds (Horne 2006). Casein coatings have the advantage of being stable over a wide range of pH, temperature, and salt concentration. They are flavourless, odourless and retard browning due to their good oxygen barrier (Tien et al. 2001) and have low water vapour permeability (Fematt-Flores et al. 2022). According to Beulah et al. (2021) adding a plasticiser such as glycerol and a firming agent to the casein coating helps to extend storage and in the loss of vitamin C in guava fruit.

Egg albumin

Egg albumin or egg white. Egg white consists of ovalbumin, ovotransferrin, ovomucoid, ovomucin, globulin and lysozyme. The most abundant protein in egg white is ovalbumin, which makes up more than 50 % of the protein in egg white (Mine 1995).

Egg albumin has good functional properties such as emulsification, foaming, heat fixation and adhesive properties. Dried egg white protein powder is used to form the coating. Inter and intramolecular disulfide bonds and hydrophobic bonds are involved in the formation of the coating. The quality of the resulting coating can be influenced by pH (Gennadios et al. 1996). According to Amal et al. (2011), pure albumin coating forms opaque coatings. The addition of lipid to albumin coating increased the tensile strength, and elongation at break, and decreased the permeability to water vapour.

Gelatin

Gelatin is obtained by the hydrolytic degradation of collagen. Two methods of pre-treatment are used in the production of gelatin. Either it is treated with acid or alkali before extraction. Depending on the pre-treatment method, the final gelatin has different electrical properties (Young et al. 2005). The pre-treatment results in warm water-soluble collagen. To form gelatin, the collagen is dissolved in warm water (over 40 °C) where the triple helix of collagen is disrupted (Ross-Murphy 1992). Gelatin is used as an emulsifier, foaming agent, colloid stabiliser, biodegradable coating forming material and micro encapsulant (Gómez-Guillén et al. 2011).

Gelatin-based coatings have good mechanical properties but poor water vapour barriers. The gelatin coatings themselves are brittle, so it is necessary to add a plasticiser. The addition of plasticiser makes the coating more flexible, more transparent and increases elongation at break (Jongjareonrak et al. 2006). The combination of gelatin and starch is very common. When these two ingredients are combined, the coating has a higher thickness, mechanical resistance, and transparency (Fakhouri et al. 2015). In the case of a combination of gelatin with mint essential oil, the coating has an antifungal effect, lower water vapour permeability, lover tensile strength (Scartazzini et al. 2019), slower pH change, weight loss and colour change (Aitboulahsen et al. 2018).

Lipid-based edible coating

Lipid coatings have been used for many centuries (Hardenburg 1967). Coatings include waxes, natural oil and fat and resins. They can either be of plant origins, such as vegetable oils or some waxes (e.g., carnauba wax, candelilla wax) or animal or insect origin, such as fats and certain waxes, for instance, beeswax (Rhim & Shellhammer 2005).

Because of their hydrophobic qualities, lipid coatings are generally used as an excellent moisture-retention barrier. Another positive aspect is the slowing down of respiration as well as a better appearance and the production of gloss on fruits and vegetables (Dhall 2013). The disadvantage of lipid coating is the formation of thicker and more brittle layers due to its hydrophobic nature (Hassan et al. 2018). Generally, as hydrophobicity increases, permeability to water vapour decreases (Bourtoom 2008). Therefore, lipids need to be combined with other attractants such as proteins or polysaccharides (Rhim & Shellhammer 2005). The addition of lipids to the coating can improve the basic capabilities of the coating. Lipids are commonly used as emulsifiers to increase stability and ensure good adhesion or as plasticisers to enhance mechanical properties (Yousuf et al. 2022).

Waxes

Waxes are the most used lipid for coating production. They can be divided based on their origin. Waxes can be of natural origin (such as beeswax, carnauba wax, candelilla wax and others) or synthetic and mineral waxes (such as paraffin wax, montan wax and polyethene wax). Carnauba wax is commonly found in nature and is derived from the leaves of the palm tree (*Copernica cerifera*). It is the hardest and has the highest melting point of the permitted waxes. It is used to raise the melting point, and for its hardness, toughness, and gloss. Polyethene wax serves as an alternative to carnauba wax. It is produced through the oxidation of polyethene, which is produced as a by-product of petroleum production. It is used to produce emulsion coating (Hall J 2012). Beeswax is extracted from the cells of the hive. There are two types of wax available: white and yellow. These are some examples of a few waxes commonly used and allowed in the European Union.

From a chemical point of view, waxes are esters of long-chain aliphatic acid and long-chain aliphatic alcohol. As a result, most natural waxes have emulsifying properties (Rhim & Shellhammer 2005). Waxes are used for enhancing appearance and as a barrier against gases and humidity (Dhall 2013). The main reason for the use is the hydrophobic properties of the material. It is more resistant to moisture transport than other lipid or nonlipid coating (Rhim & Shellhammer 2005). Other benefits include protection against chilling injury (Perez-Gago et al. 2002) and slowing respiration rate. If misused, the slowing of respiration may have a negative impact on the shelf life. If a thick layer of wax is applied, alcoholic flavours can be produced due to anaerobic fermentation (Yousuf et al. 2022). Another issue that arises from the application of a thick layer is the requirement to remove this layer before ingestion. Only a thin layer is thought to be edible (Bourtoom 2008).

Natural oils and fat

Fats and oils are of plant or animal origin. They are chemically similar but physically different. The main components are triacylglycerols, esters of fatty acids with glycerol. Long-chain triacylglycerols are insoluble in water. In shorter chains, triacylglycerols are partially soluble in water. The melting temperature is affected by the degree of saturation. Saturated ones have a much higher melting point than unsaturated ones (deMan 2008). Water vapour permeability is affected by chain and degree of saturation.

Oils have a higher polarity than waxes but can form a stable monolayer on the surface (Rhim & Shellhammer 2005). Oils include sunflower, olive, rapeseed, corn, and mustard oils. These oils are widely available, inexpensive, safe, and non-volatile. Their use can have a positive health effect (Yousuf et al. 2022). In coating formation, they are more likely to be used in combination with other substances such as chitosan. Khalifa et al. (2016) studied the coating formed from olive oil residues and chitosan and its effect on the preservation of the quality of refrigerated apples and strawberries. Olive oil residues had a positive effect on the preservation of the quality of refrigerated fruits. The addition of olive oil to the chitosan coating led to an improvement in the lower activity of injured cell walls and increased antifungal activity.

Resins

Resin is an exudate produced by plants, mostly in response to damage or infection. Most resin comes from coniferous trees, mainly in the Araucariaceae and Pinaceae families (Langenheim 1990). Resin coatings are the least permeable to gases. This can result in anaerobic respiration and reduces food quality (Hagenmaier 2005). On the other hand, forms a good moisture barrier and is used to produce a gloss on the surface and improve the appearance of the fruit (Hagenmaier & Baker 1995). Resin can also be produced by insects such as *Laccifer lacca* which produces shellac resins. A complex combination of aliphatic alicyclic polymers of hydroxyl acid makes up shellac. It is compatible with the majority of waxes and soluble in alcohols and alkaline solutions. The shellac coating creates a better barrier against water vapour and produces a glossy surface (Hall 2012). Based on Alleyne & Hagenmaier (2000) study, the shellac coating has a higher gloss, strength, and ethanol content. According to ES 1333/2008, shellac is one of the substances that can be used for the surface treatment of fruit (European Parliament 2008). Other types of resins include cumarone indene and wood rosin (Dhall 2013).

2.4.5. Methods of edible coating applications

The effectiveness of the coating is influenced by the method of application. The method of application of coatings depends on the characteristics of the food such as size, shape, and the desired thickness of the fruit (Debeaufort & Voilley 2009). Furthermore, the surface tension, viscosity and density of the coating (Andrade et al. 2012). The common method of application is dipping and spraying (Fig. 6). Spreading is another method that can be used (Fig. 6). These methods are described in more detail below.

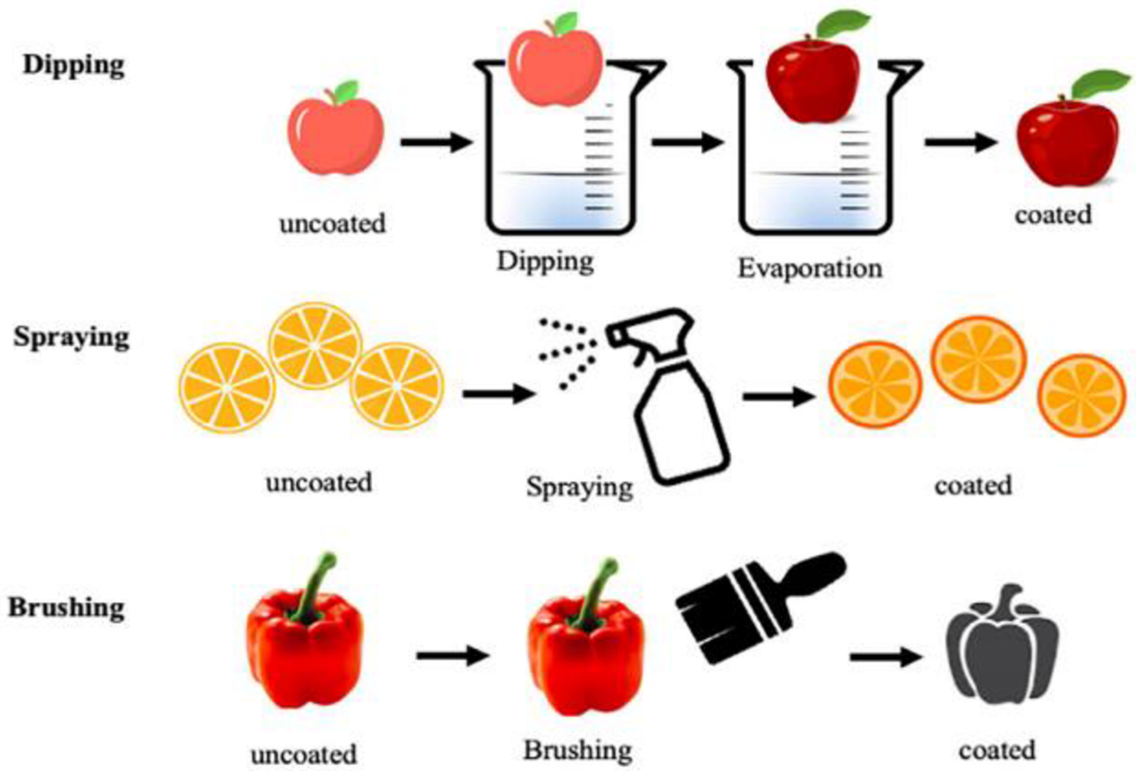

Figure 6. Methods of applying edible coatings. Source: (Jafarzadeh et al. 2021)

Dipping method

This method is very common when a coating is applied to fruit. The fruit is soaked in a container with a solution. Here, the food is coated with liquid and then dried. After drying, a layer of coating forms on the surface (Tharanathan 2003). The dipping method is used for a thick coating layer (Dhanapal et al. 2012). This can negatively affect respiration (Andrade et al. 2012). The density, viscosity and surface tension of the solution influences the thickness of the coating (Cisneros-Zevallos & Krochta 2003b). Another disadvantage of this method is the accumulation of debris or rotting organisms in the soaking vessel, which could affect the properties of the coating or dilute the coating (Andrade et al. 2012). The fruits are soaked for 5 – 30 seconds (Dhanapal et al. 2012).

Spraying method

Spraying is the most frequently used method for low-viscosity coatings. For high-viscosity coatings, the dipping method is used rather than spraying (Dhanapal et al. 2012). When the viscosity of the solution is adjusted, it is possible to form a thin layer of the coating on the surface. The thickness of the coating can be effectively regulated with this method. This method can be used to apply a coating over larger areas or in multiple layers (Andrade et al. 2012). The quality of the coating is influenced by the spray gun, nozzles, temperature, polymer solution, flow rate and humidity. The coating is also influenced by time, temperature, and drying methods. There are several ways to apply this method. One is the classic spray system which produces a fine coating. The droplets are distributed up to 20 micrometres in size. An additional is electrospraying, which forms uniform particles smaller than 100 nm are formed (Skurtys et al. 2010).

Spreading

Spreading is also called brushing. During the process, the solution is spread over the surface of the fruit. Subsequently, the surface becomes drier (Valdés et al. 2017). The spreading of the solution is influenced by the surface of the fruit, temperature, and humidity. Furthermore, the viscosity, surface tension and density of the solution applied to the surface. Solutions with low viscosity spread best (Kumar & Prabhu 2007). According to Ayranci & Tunç (1997), the brushing method reduces moisture loss better than the dipping method.

3. Aims of the Thesis

The aim of this work was to compare the effect of various natural waxes and the modes of their application as an edible coating on the weight loss of mango and its shelf-life.

4. Material and Methods

4.1. Fruit material

The mangoes were from Empacadora de frutos tropicales sac – 'Empafrut', located in Peru. The fruits were harvested on 24th January 2023. Afterwards, they were transported to the Czech Republic, where the untreated mangoes were stored until 28th February 2023 in Titbit's storage facilities. All mangoes were stored in the same conditions. The mangoes were in good condition. Only some of the fruit had scratches. These were caused either by transport or harvesting. The selection of mangoes for the experiment was at the same stage of ripening, size and colour.

4.2. Application of waxes

The waxes for the experiment were shellac wax with dry matter content of 5.5 %, Shellac wax with a dry matter content of 10.20 % and carnauba wax (Fig. 7). Each wax was applied to 10 samples by spraying. Firstly, the samples were described for better orientation between the results. Subsequently, they were placed on an iron structure. Then was the actual application. The application was by spraying (Fig. 8). The coating was applied on all sides and allowed to dry. After the liquid wax dried, the fruit was turned over and the coating was applied from the other side again from all sides. For all waxes except carnauba wax, one spray from all sides was sufficient. For the carnauba wax, a thicker coat was applied. The application was sprayed twice in one place. After coating was applied, the samples were left to dry. After drying, the samples were weighed. In the experiment, 8 more specimens were used to apply the 5.5 % shellac but with a different application method. 4 specimens were applied by dipping and the other 4 by spreading (Fig. 8). During the dipping process, wax was poured into a bag and fruit was dipped into it and then dried. The brushing was done using a brush. After the sample was coated with a coating, it was left to dry. The finished samples were placed in a refrigerator. There, they were stored for 30 days at a temperature of 9 °C.

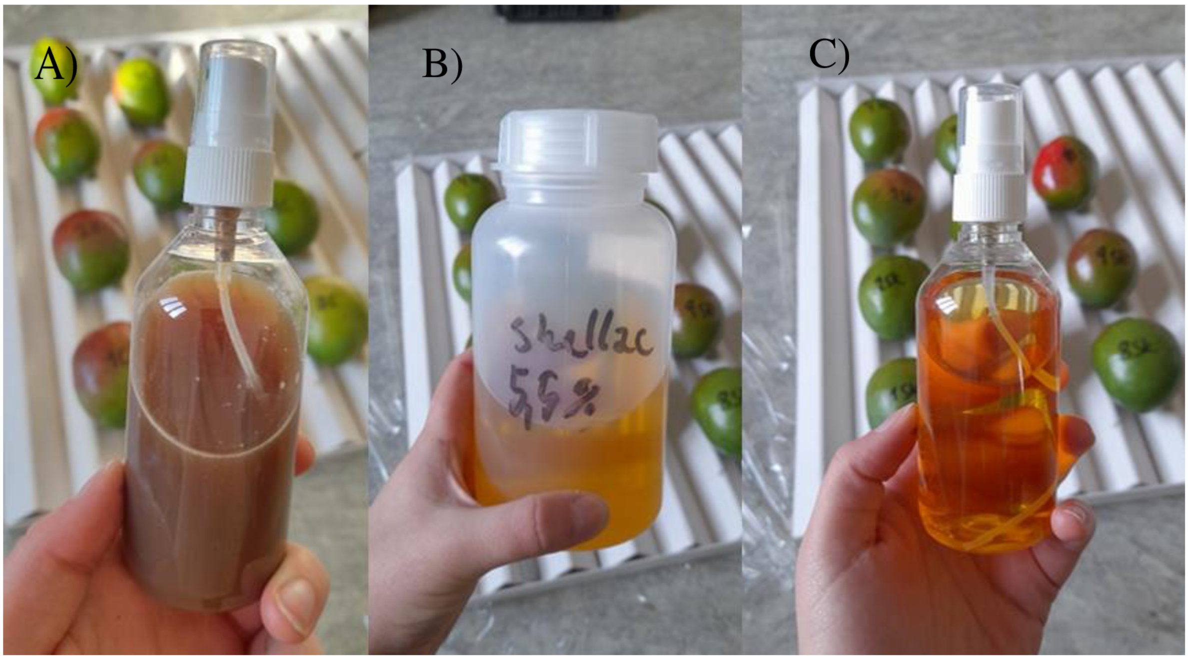

Figure 7. Applied coatings A) carnauba wax, B) shellac 5.5 %, C) shellac 10.20 %.

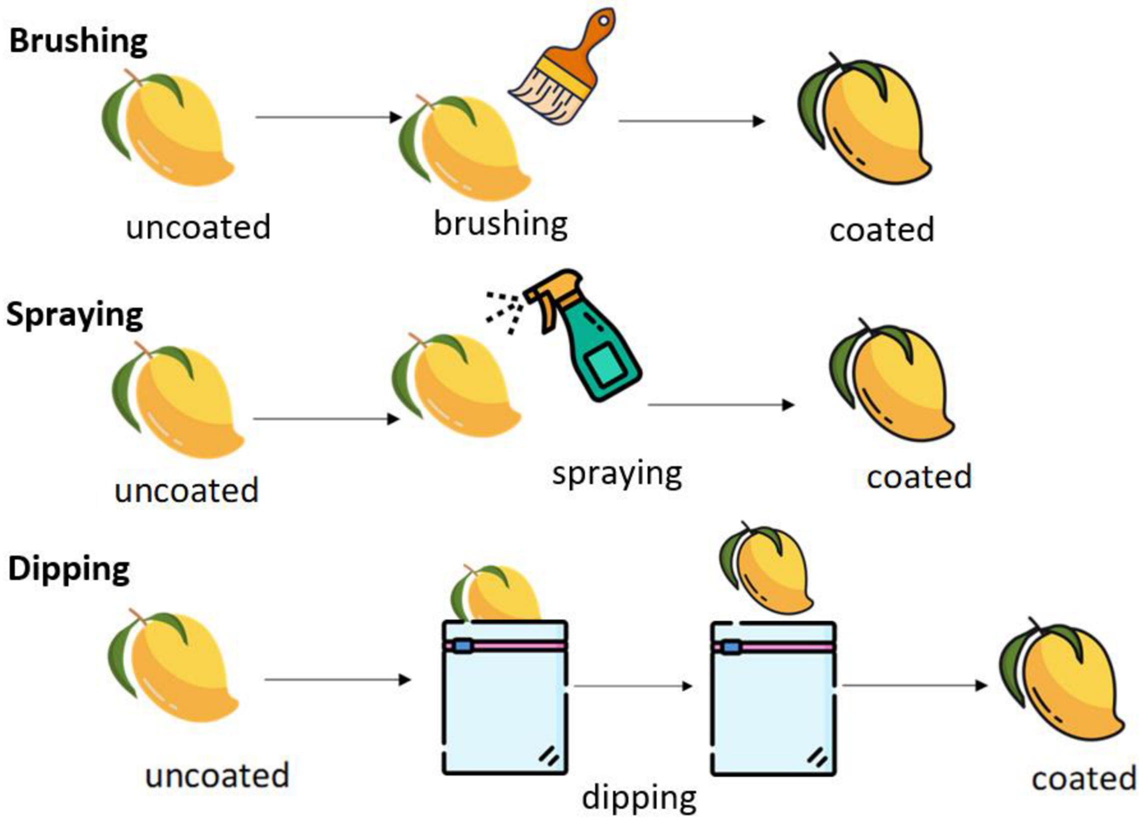

Figure 8. Application methods of edible coatings.

4.3. Weight loss

Weight loss was evaluated using a digital scale. The observation was carried out for 30 days. Every 3rd or 4th day at approximately the same time, the samples were weighed, and the results noted. Each fruit had a tag on it to prevent any mistakes. The results were then processed and compared with the control samples and with each other. Weight loss was calculated as the percentage loss from initial weight, using the formula: $\frac{(\text{average of day } 0 - \text{average of day } n^{th})}{\text{average of day } 0} * 100$.

5. Results

Each sample was weighed on the third or fourth day for 30 days. Appendix 1. shows a table with the results. The samples observed varied in coating type and application. After processing the collected data, it was evident that the coated samples had lower weight loss than the control samples. Control samples had weight loss after 30 days 4.21 %. The lowest loss was observed for shellac 5.5 %. After 30 days of weighing, the weight loss was 2.60 % for shellac 5.5 %. As for the 10.20 % shellac, it had lower losses than the 5.5 % shellac until day 27. On day 27, a clash occurred, and the shellac coatings had the same weight loss (2.31 %). After day 27, a change occurred and the 10.20 % shellac started to have higher losses than the 5.5 % shellac. The final weight loss of the 10.20 % shellac was 2.63 %. Both shellac coatings produced a gloss on the surface which created a nice appearance. The least effective in weight loss was carnauba wax, where weight loss within 6 days was the same as the control. From the 6th day onwards, the carnauba wax showed a decrease in weight loss (1.32 %) compared to the control samples (1.44 %) where there was an increasing loss. The final weight loss at 30 days was 3.57 % for carnauba wax.

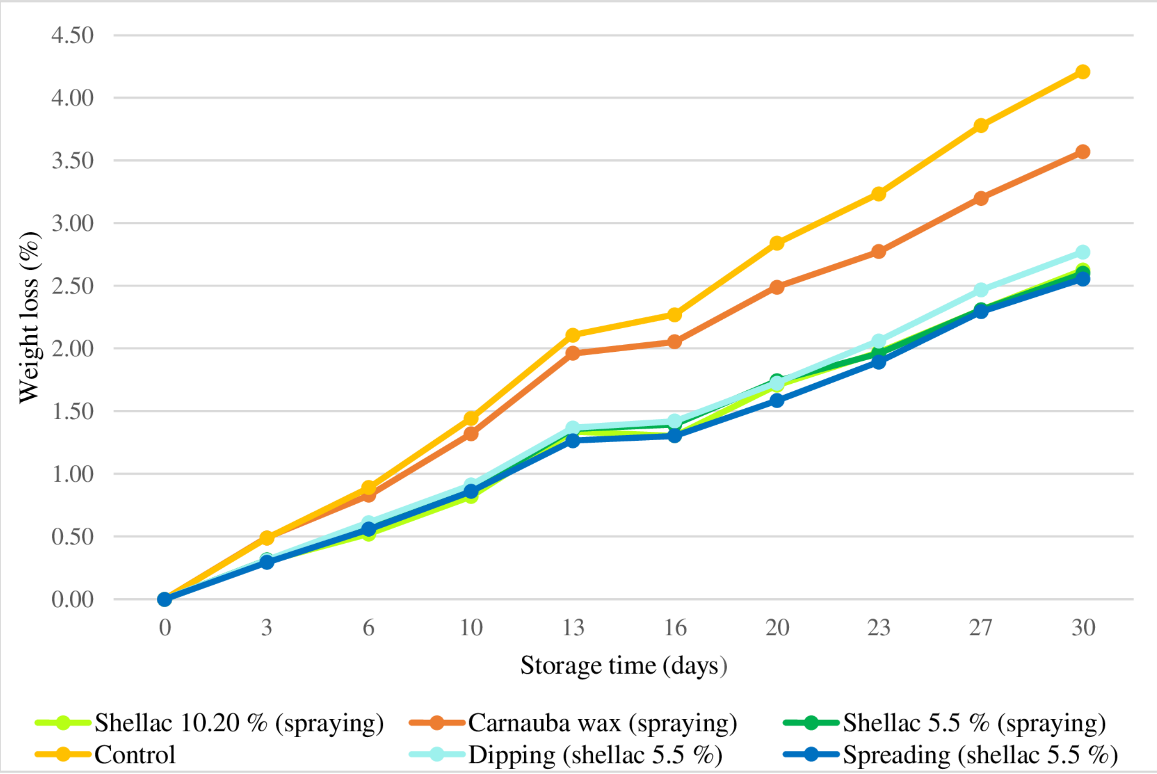

Figure 10. Percentage weight loss of mango fruit over 30 days of storage.

Regarding the method of application, the lowest weight loss was recorded for mangoes applied by the brushing method, where the loss at the end of weighing was 2.56 %. Mangoes that were applied by the dipping method had the worst result. By the 20 days of weighing, the dipped mangoes showed little difference in performance from spray-applied mangoes. After 20 days, there was an increase in weight loss in dipped mangoes from 1.72 % to 2.06 %. The sprayed mangoes, on the other hand, showed a reduction in weight loss and approached the spreading in their results. By day 27, there was a difference in weight loss of 0.16 % between dipped and sprayed mangoes. When applied by spraying, the mangoes had the best appearance and the coating on the surface was not noticeable compared to the spreading application where the coating on the surface was visible (Fig. 9). At the end of weighing, the loss for spraying was 2.60 %. which is only 0.04 % higher compared to the spread. All the results are shown in a graph showing the percentage weight loss after 3 to 4 days of weighing (Fig. 10).

Figure 9. The visible coating on the surface of the fruit.

After 30 days the coated mango was still hard but nicely coloured. In contrast, the control samples showed minimal colouration and were relatively soft. After 20 days, one mango showed obvious dehydration, which was noticeable in appearance (Fig. 11). Dehydration also started after day 30 in one sample treated with carnauba wax. Further defects in appearance were observed in 2 mangoes that had a shellac coating of 5.5 %. In these samples, the rot started to form (Fig. 12).

Figure 11. Dehydration of the fruit.

Figure 12. Initial rot on the mango fruit.

6. Discussion

Mangoes are a perishable fruit (Yanik Kocak et al. 2019). One possibility to extend shelf life and maintained the quality of the fruit is to use edible coatings that create a barrier to the passage of gases, solutes and moisture. The loss of water is one of the critical factors in prolonging storage and maintaining fruit quality. Even a subtle weight loss can result in postharvest deterioration (deterioration in appearance, composition and food quality) that can result in an economic loss (Nunes & Emond 2007). Earlier Nunes & Emond (2007) reported that in the case of untreated mangoes that were stored at 20 °C and 85-90 %, there was noticeable softening after 2 days and the weight loss was 1.5 %. After 5 days, the mangoes were overripe, and the weight loss reached 4 %. In general, if the fruit reach 5 % weight loss, the loss will be visible on the fruit. The fruit then loses quality and may become unmarketable (Ministry of Fisheries et al. 2004). Visual loss can occur even at 4 % weight loss. The short shelf life under natural conditions is confirmed in this case. 4 % weight loss occurs in untreated mangoes after approximately 30 days of storage under controlled conditions (Elhefny et al. 2012). The same was the case for control samples where only temperature was observed. The control mangoes had a weight loss of 4.21 % after 30 days of storage at 9 °C. Due to the non-control of humidity during storage, dehydration occurred in one fruit. At 30 days, shrivelled skin began to appear on other fruits. Therefore, it is likely that was low humidity in the refrigerator where the mangoes were stored, which promoted the dehydration of the fruit.

Compared to untreated mangoes, mangoes on which the coating (shellac and carnauba wax) was applied had much lower weight loss even after 30 days of storage. The weight loss after 30 days ranged from 2.56 % to 3.57 %. The barrier formed on the surface helped to keep the moisture in the atmosphere high, thus reducing weight loss. The hydrophobic nature of the lipids, which include shellac and carnauba wax, probably also helped to reduce weight loss (Bourtoom 2008). Signs of dehydration only appeared up to day 30 on one mango where carnauba wax was applied. Of the coatings, it was the carnauba wax that had the greatest loss. As of day 30, the weight loss was 3.57 %, only 0.68 % less than the control samples. According to Hoa & Ducamp (2008), carnauba wax-based coatings achieved a loss of 3.57 % and 2.90 % in 6 days when stored at 21-31 °C and 65-75 % humidity. On the other hand, when stored under cooler conditions (10 °C, 90-95 % humidity), the loss was 3.8 % in 17 days. This confirms that a 1 °C reduction in temperature can help reduce weight loss and increase shelf life without damaging the fruit. Although at 9 °C the values of carnauba wax were low compared to other storage experiments when compared to shellac 5.5 % and 10.20 % the values of carnauba wax were quite high. Compared to the carnauba wax which had a loss of 3.57 % the loss for the 5.5 % shellac was 2.60 % at 30 days and for the 10.20 % shellac was 2.63 %.

When the results were compared with other studies, it was found that in most cases carnauba wax had lower losses. Dou & Gmitter (2007) and Dou (2004) reported lower losses for carnauba wax than for shellac coating in their studies. In both studies, the fruits were stored at 4 °C. According to Miranda et al. (2021) when citrus was stored at 10 °C for 14 days, carnauba wax again had lower losses, than shellac coating. In all studies, although carnauba wax had lower losses, the differences were not significant. In contrast, Oosthuyse (1997) reported a difference in results between varieties for mangoes stored at 12.5 °C for 28 days. He compared 3 mango varieties (Sensation, Kent, Keitt). Only in the 'Sensation' variety was the weight loss of the carnauba wax lower than that of the shellac coating. In the case of 'Kent' and 'Keitt', it was the shellac coating that had the lower weight loss. Again, the difference was not very significant. Only in the 'Keitt' variety was the difference significant. Relatively low weight loss during storage at 4 °C was reported by Zhou et al. (2008) when shellac coating was applied to pears. Where after 60 days of storage the loss was 5.82 % and after 30 days the loss was approximately 2.80 %. Conversely, de Carvalho et al. (2020) reported in the storage of an orange to which carnauba wax was applied, after 60 days of storage at 3 °C the loss was 8.4 % and after 20 days the loss was approximately 2.50 %. In this case, the loss was very similar to that of both shellac-coated mangoes (5.5 % and 10.20 %) and carnauba wax-coated mangoes stored at 9 °C. The differences between carnauba wax and shellac coating may be influenced by the coating formulation of the supplier companies, temperature, fruit variety, coating application method or chemical properties.

In the case of room temperature storage, carnauba wax seemed to be a preferable option. According to Navarro-Tarazaga et al. (2007) when carnauba wax was applied to tangerines, carnauba wax had a weight loss of 2.8 % and shellac had a loss of 3.8 %. The tangerines were stored for 7 days at 24 °C. Similar results were reported by Chittarom & Siriphanich (1993) who applied the coatings to tangerines. These were stored at room temperature for 14 days. After 14 days, the weight loss using carnauba wax was

5.0-7.6 % and shellac around 9 %. According to the information obtained, it can be assumed that it is the shellac coating that has better properties for maintained quality when stored at lower temperatures. On the other hand, carnauba wax has better storage properties at room temperature.

As far as the shellac coating is concerned, dry matter concentration can also affect the coating. At a concentration of 10.20 %, the shellac coating had lower losses up to day 27 (2.31 %). After day 27, the loss began to increase (2.63 %). Conversely, 5.5 % shellac had lower losses (2.60 %) than 10.20 % shellac from day 27 onwards. Thus, it is the 10.20 % shellac that seems to be more effective for shorter storage periods, up to approximately days 20-27. On the contrary, for long-term storage, 5.5 % shellac seems to be more effective. The weight loss was also influenced by the method of application of the coating. The most commercially used application method is spraying. Due to its easy application, the thin layer is applied, and the coating is spread uniformly on the surface (Andrade et al. 2012). In terms of effectiveness, the weight loss was 2.60 %. Thus, the loss was 0.04 % higher compared to the brushing. The brushing had the best results, with a loss of 2.57 % after 30 days. Although the effect was excellent, the coating was still visible after drying on the surface. Another disadvantage was the difficulty of application and the influence of the human factor on the quality of the coating application. The dipping had the worst results, with a loss of 2.77 %. This could be due to the formation of a thick layer or dilution of the solution (Andrade et al. 2012).

7. Conclusions

The work aimed to compare the effect of different waxes on weight loss and shelf-life. The results showed that by applying coating on the surface of mangoes weight loss is reduced. Shellac 5.5 % coating had the lowest final weight loss (2.60 %). However, during the observation period from the beginning to the 27th day, 10.20 % of shellac had lower weight loss than 5.5 % shellac. On the 27th day, both shellac coatings had the same weight loss (2.31 %). After day 27, there was an exchange and the 10.20 % shellac had a higher weight loss (2.63 %) than 5.5 % of shellac (2.60 %). Carnauba wax had the worst results of the coatings, with a final loss of 3.57 %. The control samples had a loss of 4.21 % on day 30 of observation.

The experiment also observed 3 methods of application and their effect on weight loss. In this case, the spreading had the best overall weight loss (2.56 %), but the coating was visible on the surface after drying. Spraying had similar final results (2.60 %) to spread. Up to day 20, spraying had weight loss rather similar to dipping. From day 20 onwards, spray weight loss decreased and approached spreading (2.56 %). The final loss for spay was only 0.04 % higher than the spreading. The dipping method had the worst results (2.77 %).

Based on these data, it would be recommended to use a shellac 10.20 % for short-term cold storage. In contrast, the 5.5 % shellac should be used for long-term cold storage. Both coatings have shown good potential for use as storage coating. Therefore, further studies should be conducted to confirm the results.

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Appendices

List of the Appendices:

Appendix 1: Weight loss of mangoes from 28.2.2023 to 30.3.2023

Sample number	Shellac 10.20 % (spraying)									
	Date 28.2.2023	Date 3.3.2023	Date 6.3.2023	Date 10.3.2023	Date 13.3.2023	Date 16.3.2023	Date 20.3.2023	Date 23.3.2023	Date 27.3.2023	Date 30.3.2023
	g									
1	430.9	429.7	428.9	427.5	425.7	425.7	424.3	423.3	422.0	420.8
2	431.8	430.6	429.6	428.2	425.8	426.3	424.7	423.6	422.0	420.6
3	452.6	451.2	450.1	448.8	446.5	446.3	444.2	443.0	441.3	439.7
4	426.3	425.0	424.1	422.6	421.4	420.6	419.0	417.8	416.3	415.1
5	436.5	435.4	434.7	433.6	430.7	431.8	430.3	429.4	428.3	427.1
6	459.7	458.0	456.6	454.7	451.5	451.6	448.6	447.2	445.1	443.1
7	459.5	458.4	457.6	456.4	454.0	454.6	453.1	452.1	450.9	449.5
8	462.8	461.4	460.1	458.7	455.7	456.2	454.3	452.5	450.7	448.9
9	408.2	406.9	405.9	404.7	402.5	402.7	400.9	399.7	398.4	397.3
10	445.7	444.4	443.6	442.7	441.1	440.7	439.3	438.4	437.2	436.0
Average	441.40	440.10	439.12	437.79	435.49	435.65	433.87	432.70	431.22	429.81
Weight loss (%)	0.00	0.30	0.52	0.82	1.34	1.30	1.71	1.97	2.31	2.63

Sample number	Shellac 5.5 % (spraying)									
	Date 28.2.2023	Date 3.3.2023	Date 6.3.2023	Date 10.3.2023	Date 13.3.2023	Date 16.3.2023	Date 20.3.2023	Date 23.3.2023	Date 27.3.2023	Date 30.3.2023
	g									
1	440.8	439.2	438.2	436.7	434.8	434.6	433.6	432.2	430.8	429.6
2	442.5	440.7	439.4	437.7	435.0	435.0	433.2	431.5	429.6	428.0
3	474.4	472.8	471.8	470.4	468.4	468.1	466.3	465.6	464.0	462.7
4	444.5	443.3	442.3	440.9	439.2	439.0	437.5	436.7	435.2	434.1
5	461.7	460.3	459.1	457.7	455.6	455.6	453.7	453.0	451.5	450.2
6	467.5	465.9	464.6	463.0	460.5	460.1	458.5	457.2	455.5	453.9
7	448.1	446.8	445.7	444.5	442.1	442.0	440.5	439.7	438.2	437.1
8	470.5	469.1	467.8	466.2	463.6	463.6	462.0	461.0	459.3	457.7
9	428.9	427.6	426.4	425.1	423.0	422.7	421.2	420.1	418.5	417.3
10	452.4	451.3	450.4	449.5	447.5	447.4	445.7	445.3	444.0	442.8
Average	453.12	451.70	450.57	449.17	446.97	446.81	445.22	444.23	442.66	441.34
Weight loss (%)	0.00	0.31	0.56	0.87	1.36	1.39	1.74	1.96	2.31	2.60

Sample number	Control									
	Date 28.2.2023	Date 3.3.2023	Date 6.3.2023	Date 10.3.2023	Date 13.3.2023	Date 16.3.2023	Date 20.3.2023	Date 23.3.2023	Date 27.3.2023	Date 30.3.2023
	g									
1	444.2	441.2	438.7	435.1	432.2	430.3	427.3	424.6	421.1	418.6
2	451.5	449.5	448.1	446.3	444.1	442.9	440.2	438.7	436.4	434.9
3	472.5	470.4	468.9	466.8	463.8	463.7	461.4	460.0	457.6	455.7
4	443.0	441.4	439.7	437.5	434.5	434.4	432.6	431.2	429.1	427.5
5	430.4	428.2	426.3	423.8	420.7	420.3	418.0	416.0	413.5	411.6
6	465.5	462.9	461.0	458.2	454.9	454.1	450.3	449.4	446.5	444.3
7	455.5	453.3	451.1	448.8	445.0	443.9	441.2	439.2	436.3	434.1
8	437.9	436.0	434.6	432.4	429.6	429.1	426.7	424.4	423.3	421.4
9	432.4	430.6	428.9	426.9	424.0	423.8	421.5	420.2	418.2	416.5
10	478.0	475.6	473.6	470.2	467.2	466.1	463.7	461.4	458.6	456.5
Average	451.10	448.91	447.09	444.60	441.60	440.86	438.29	436.51	434.06	432.11
Weight loss (%)	0.00	0.49	0.89	1.44	2.11	2.27	2.84	3.23	3.78	4.21

Sample number	Carnauba wax (spraying)									
	Date 28.2.2023	Date 3.3.2023	Date 6.3.2023	Date 10.3.2023	Date 13.3.2023	Date 16.3.2023	Date 20.3.2023	Date 23.3.2023	Date 27.3.2023	Date 30.3.2023
	g									
1	458.4	456.0	454.2	451.7	449.8	448.1	445.7	444.5	442.4	440.6
2	457.6	456.0	454.9	453.2	450.5	450.5	449.2	448.7	447.3	446.0
3	462.2	459.8	458.5	456.3	454.2	453.2	450.9	450.1	448.0	446.3
4	409.6	407.2	405.4	403.0	399.7	399.3	397.2	395.7	393.6	391.8
5	435.9	433.3	431.5	429.1	425.7	425.5	423.5	422.2	420.6	419.0
6	473.6	471.6	470.1	467.9	464.3	464.4	462.5	461.2	459.1	457.2
7	471.4	469.3	467.6	465.4	462.5	462.1	460.3	458.6	456.7	455.0
8	420.2	417.8	416.5	414.3	411.3	411.1	409.2	407.7	405.8	404.3
9	469.7	467.8	466.3	464.2	461.2	461.2	459.3	458.0	456.2	454.5
10	455.7	453.6	452.1	449.3	446.7	446.3	444.2	442.5	440.3	438.6
Average	451.44	449.24	447.71	445.44	442.59	442.17	440.20	438.92	437.00	435.33
Weight loss (%)	0.00	0.49	0.83	1.32	1.96	2.05	2.49	2.77	3.20	3.57

Sample number	Dipping (shellac 5.5 %)									
	Date 28.2.2023	Date 3.3.2023	Date 6.3.2023	Date 10.3.2023	Date 13.3.2023	Date 16.3.2023	Date 20.3.2023	Date 23.3.2023	Date 27.3.2023	Date 30.3.2023
	g									
1	467.9	466.6	465.5	464.2	462.4	462.3	461.1	459.9	458.3	457.2
2	434.8	433.5	432.3	431.1	429.1	429.1	427.8	426.6	424.8	423.5
3	459.0	457.0	455.2	453.5	450.8	450.0	448.1	445.7	443.3	441.5
4	455.4	454.3	452.9	451.7	449.9	449.8	448.7	447.4	445.8	444.5
Average	454.26	452.85	451.48	450.13	448.05	447.80	446.43	444.90	443.05	441.68
Weight loss (%)	0.00	0.31	0.61	0.91	1.37	1.42	1.72	2.06	2.47	2.77

Sample number	Spreading (shellac 5.5 %)									
	Date 28.2.2023	Date 3.3.2023	Date 6.3.2023	Date 10.3.2023	Date 13.3.2023	Date 16.3.2023	Date 20.3.2023	Date 23.3.2023	Date 27.3.2023	Date 30.3.2023
	g									
1	438.6	437.4	436.2	434.9	433.4	433.3	432.2	431.0	429.4	428.4
2	461.3	459.9	458.6	457.4	455.2	455.1	453.9	452.5	450.7	449.6
3	465.7	463.9	462.5	460.5	458.5	458.0	456.4	454.5	451.9	450.4
4	485.0	484.0	483.0	481.9	480.1	480.1	478.8	477.6	476.2	474.9
Average	462.66	461.30	460.08	458.68	456.80	456.63	455.33	453.90	452.05	450.83
Weight loss (%)	0.00	0.29	0.56	0.86	1.27	1.30	1.58	1.89	2.29	2.56