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Edible Coatings in Fruits: Effectiveness and Applicability: A Review

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Abstract

Fruits form an integral part of the human diet as they not only provide us with the fibre content but are a ready source of minerals, vitamins and carbohydrates. Although we have refined our production technologies to an extent that we can produce sufficient quantities of fruits still the post-harvest management and storage life of fruits is a bit of concern as the fruits are liable to spoilage due to high moisture content. For the nutritional security of our growing masses, it is essential to preserve our fruits and protect them from spoilage by using novel techniques. One such technique is to use coatings on the surface of the fruits which would act as insulation between the fruit's internal environment and the external atmosphere. An edible coating has been shown to act as a shield on the surface of the fruit, change the internal environment, reduce loss of water and prolong fruit shelf life. This review highlights the advances made in the field of coating technology and its impact on the post-harvest life of fruits. Preventing post-harvest losses is the most important challenge in horticulture commodities. The edible coating is a sustainable alternative to traditional plastic packaging, which is non-biodegradable in nature and pollutes the environment. Functional edible coatings that can alter the inner environment of fruits while also increasing the food's value have been produced and developed.

Keywords: Coatings, Fruits, Nutrition, Quality, Shelf Life, Storage

1. Introduction

Fruits are important components of a daily diet and have become increasingly common in recent years among the general public. Vitamins, basic minerals, enzymes, bioflavonoids, dietary fibres and flavouring compounds that are susceptible to biotic and abiotic stresses, are all found in them[1]. The post-harvest quality of fruits is highly affected by the pre-harvest and harvest activities which include orchard management practices as well as how fruit is harvested. Postharvest practices like coatings, Modified Atmospheric Packaging (MAP) and Controlled Atmosphere (CA) storage are in place for shelf life enhancement and quality retention by hindering the bio-chemical process like ripening, respiration and senescence[2].

Fresh fruit contains mostly 80-90% moisture at its optimum freshness level. The value of fresh fruit is determined based on its mass. Moisture loss is directly related to mass loss, as the moisture reduction result in weight loss which can lead to economic losses[3]. Most of the coatings are prepared in liquid form thus increasing the surface area and can equally spread out to the body of fruits. Coatings form a layer which resists the major exchange of factors which leads to over-ripening and senescence further avoiding the uptake of oxygen which affect the produce quality and spoilage[4]. It has been seen that edible coatings not only affect respiration, ethylene production and senescence, it also affects the various biological, physical and chemical properties of the product like firmness, appearance, microbial activity, and

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Total Soluble Solids (TSS). Edible coatings are as much effective as MAP[5].

Advances have been made in the composition and application procedures of coatings, which has led us to multiple approaches using nanotechnology or nano-coatings[6]. Nano-emulsion is the most promising technique for improving the qualitative characteristics of fresh-cut fruit since it can encapsulate antioxidants, nutraceuticals, colour, flavour and antimicrobial activity as nanocarriers. The technology can operate as active chemical reservoirs safeguarding them and regulating their release in response to particular triggers[7]. Various post-harvest issues related to horticulture produce have been researched in recent years, with the majority of solutions relying on the usage of newly developing nanotechnology. Nanotechnology makes use of materials at the nanoscale (less than 100 nm), making use of variations in physicochemical qualities between these materials and those at a greater scale. It represents a new tool for packaging material for the packaging industry which guarantee promising results[8].

2. Classification of Edible Coatings

Edible coatings or films are divided into four basic types viz. proteins, polysaccharides, lipids, and composites as seen in Figure 1. They are thin structured layers entirely covering the surface of the fruit. They provide safety to the horticultural produce with shelf life-enhancing properties. They can slow the transit of moisture content and losses in volatile chemicals, lower respiration rates, and prolong changes in textural qualities[9]. The selective gas permeability ratio is higher in these coatings as well as they are barriers to good fats and oils when compared to the synthetic ones[10]. They typically serve as good transporters as antioxidants and antibacterial agents for food additives[11]. The handling properties of a product along with its mechanical integrity are enhanced by edible coatings. Replacement of synthetic packaging films can easily be done by a few stand-alone coatings with good mechanical qualities for some of its applications.

3. Effects of Coatings on Firmness

Polygalactonurase (PG), a hydrolytic enzyme liberated during the cutting of fruits, degrades the middle lamella cell wall, causing the fruits to lose firmness. When moisture depletion occurs, the turgor pressure decreases, resulting in shrivelling. An edible shellac coating preserves the firmness of oranges[13]. In general, fruit firmness decreases as the storage time progresses. Coatings with paraffin wax and chitosan have been documented to reduce the softness of papaya fruits compared to uncoated fruits which show the lowest firmness[14].

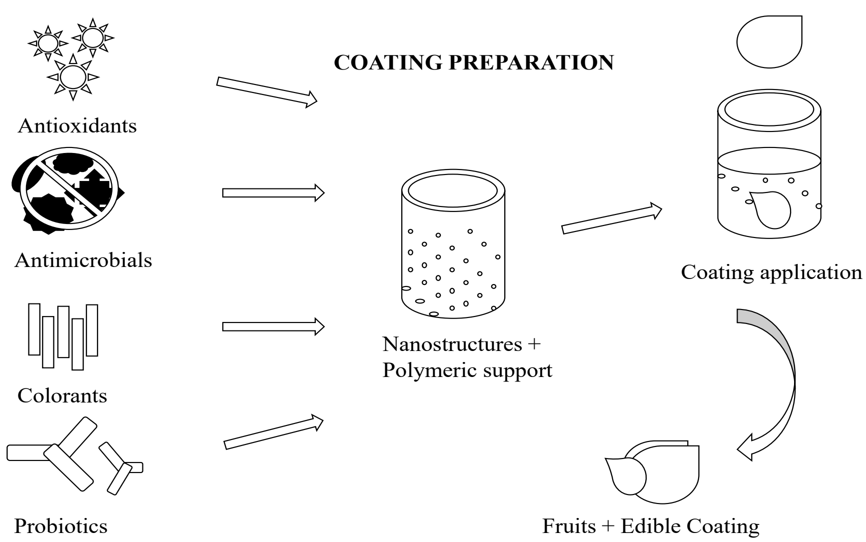
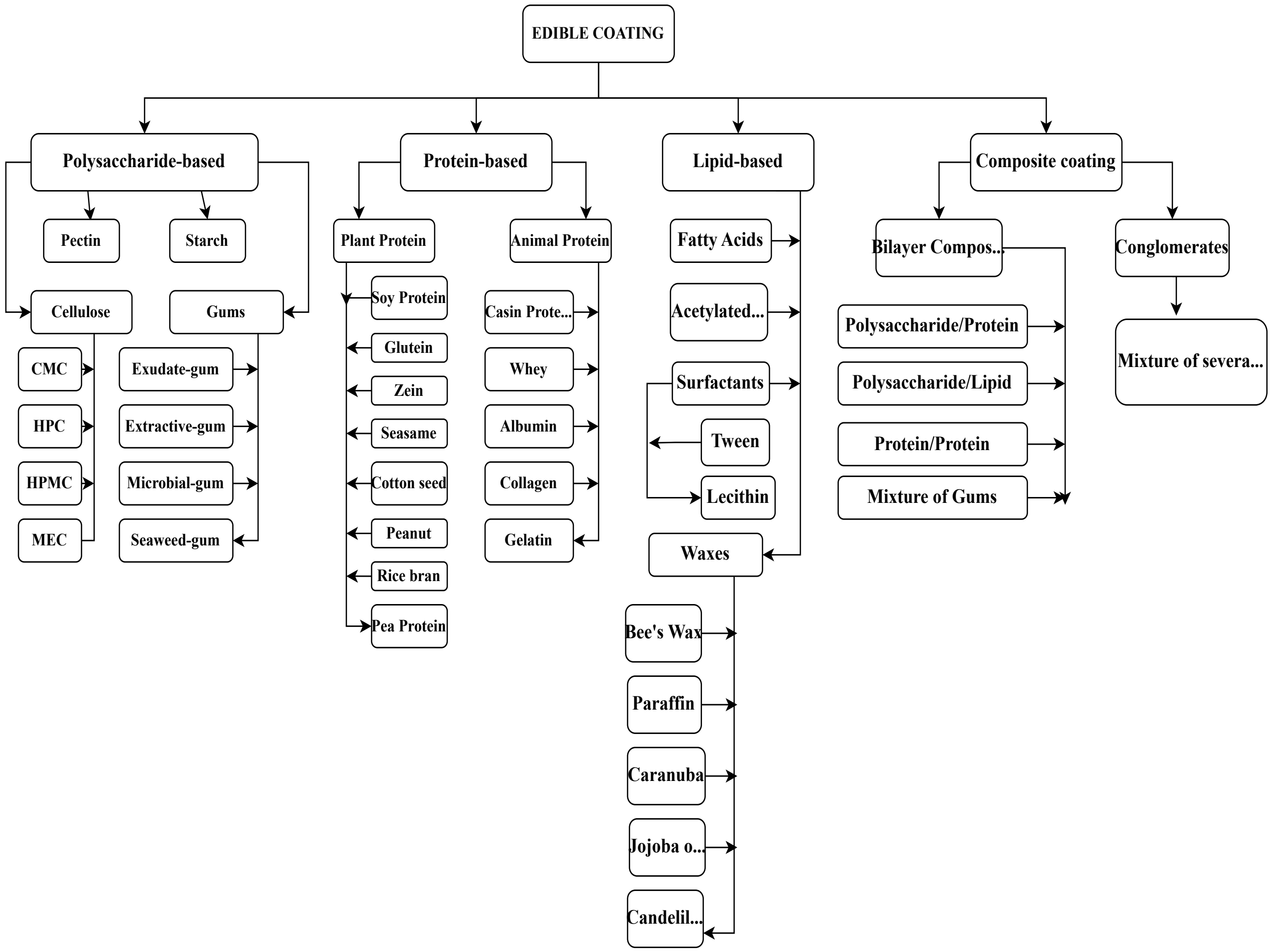


Figure 1. Classification of edible coatings.



Source[12].

Mango fruit ripening is marked by a lack of firmness caused by pectinesterase digestion of the cell wall. Mango fruits coated with zein coating have higher firmness than uncoated mangoes. Fruit that has been picked is normally of higher quality, but it softens too easily for long-distance transport so the coating is necessary[15]. Firmness is another

Table 1. Effect of coatings on the firmness

Functional coating type	Coating material	Fruits	Effect on product	References
Salicylic acid	Arabic gum	'Grand Nain' bananas	Improve firmness and peel browning index with a decrease in weight loss	17
Aloe vera gel and lemon essential oil	Hydroxypropyl methylcellulose	Hayward kiwis	Maintain higher firmness with reduce in microbial load	18
lotus leaf extract	Sodium alginate, konjac glucomannan and starch	Goji berries	Maintain TSS, and firmness and reduce the decay rate	19

crucial aspect of fresh-cut fruit quality, as firmness reduces as weight loss rises. In pineapple, researchers found that the coated samples had a somewhat higher hardness than the control samples, according to the firmness of the samples. Coated samples were generally stiffer than control samples, and no significant changes between coated and uncoated fruit were detected during storage. The cross-linking process of the polymers causes this "firming" effect, which helps to decrease juice leakage[16]. Edible coatings have shown significant effects on the firmness of fruits as shown in Table 1.

4. Effects of Coatings on Decolouration and Browning

Browning and decolouration are two major factors that downgrade the quality and marketability of fresh-cut fruits. Browning is a big issue with apples, impacting their appearance, market price and nutritional content. In comparison to untreated apples, Aloe vera gel has an anti-browning impact on Fiji fresh-cut apples, avoiding browning for a longer period. Aloe vera gel works as a plasticizer and prevents degradation, according to research[20].

Propolis is an organic polymeric compound gathered by honeybees from the leaf buds of many tree species and it is a complex collection of chemical ingredients. During cold storage, HPMC coatings prevent weight loss and browning of muscatel table grapes while also increasing their gloss and microbiological safety and limiting the increase in oxygen consumption. Due to improved film opacity, propolis insertion boosted the colour luminosity of the grapes, which helps to standardise the grapes' appearance, which is regarded as favourable for their quality[21]. Fruits with active coatings including antioxidants and anti-browning chemicals have better quality during postharvest storage as shown in Table 2.

According to the researchers, a delay in browning in fruits may be caused due to non-enzymatic and enzymatic reactions and further degradation of chlorophyll to pheophytin. Edible coatings having sericin as an ingredient have promising applications to fresh-cut mango and resulted in a reduction in browning enzyme production[22]. In fresh-cut papaya, the browning index fluctuated slightly up to five days as compared to those from the seventh day forward, which reached its greatest value after storing for 12 days. However, a pre-treatment with the help of a chemical solution followed by Aloe vera gel coating slowed down the growth in the browning index, resulting in a lower value at the very end of the storage period. Browning index and its general shifting pattern of values of freshly-cut papaya suggested that Aloe vera gel treatments in addition to a chemical dip would be beneficial in keeping and retaining the colour decline throughout the entire storage period[23].

Table 2. Effect of edible coatings on decolouration and browning

Functional coating type	Coating Material	Fruits	Effect on product	References
Pomegranate peel extract	Alginate and chitosan	Guava	Improved product quality and shelf-life	24
Eugenol and citral	Alginate/pectin	Raspberry	Increased antioxidant activity and phenolic content	25
Lemongrass essential oil	Carnauba wax	Grape berry	Increasing scavenging activity and total phenols	26
Cinnamon leaf oil	Pectin	Peach	Increase flavonoids and antioxidant capacity	27
Cinnamon leaf oil	Pectin	Table grapes	Increase in antioxidant capacity	28

5. Effects of Coatings on Microbial Activity

Strawberry freshness has been reduced during preservation due to its highly perishable nature which includes sensitivity to postharvest diseases caused by bacteria, yeasts and fungal infections. Aloe vera coatings efficiently reduced or suppressed microbial colonies in the current investigation compounds like acemannan of Aloe vera were responsible for antimicrobial activity in strawberries[29].

Apple is one of the prime temperate fruit crops holding a special place in the economy of temperate regions. However, the short shelf life due to high moisture content is a bit of a concern. The high moisture content of apple fruit invites high microbial activity leading to the deterioration of the harvested fruit. Efforts to check microbial activity have led to the use of nano-emulsion-based edible coatings with various ingredients. One such research highlights the use of lemon grass essential oil at varied concentrations, such as 0.1, 0.5, or 1%. Astonishingly, during 14 days of storage at 4°C, the natural microflora of fresh-cut Fuji apples were inhibited by edible coatings based on nano-emulsion[30].

Honey from the stingless bee has a lot of promise as a protective coating against anthracnose as demonstrated during the storage and transportation of papaya. According to the results, anthracnose disease was suppressed to a great extent by using edible coatings like plant essential oils, plant extracts and honey as antimicrobial agents[31]. Researchers found that cut pineapple treated with Linseed, Aloe vera and nopal cactus showed the significance of layer-by-layer edible coatings lowered bacteria levels, according to microbiological tests. The mould and yeast levels varied from 1.08 to 2.68 log CFU g1 in samples with coatings and 3.07 log CFU g1 in control non-coated samples on day 0. Moulds and yeasts, total psychotropic microorganisms along with aerobic organisms counts were greater for the treatments with non- coated i.e. control than for the coated fruits towards the end of storage. The antibacterial activity of the polymers and the barrier produced around the cut fruit surface account for the decrease in coated samples[16]. Microbial activity is suppressed by the use of edible coatings on fruits as shown in Table 3.

6. Effect of Coating on Respiration Rate

Respiration rates differ among different fruit crops and are having more kinetics when climacteric fruits are under consideration. Plums are appreciated for their visual properties like shape, texture, colour etc. Being perishable in nature, edible coatings play an important role in preserving these attributes for a longer period. Plum fruits treated with chitosan coatings have exhibited a significantly lower respiration rate as compared to non-treated fruits during storage. Chitosan can effectively reduce quality changes as well as quantity losses[36].

In Litchi, respiration rates were inhibited by chitosan coating resulting in reduced bio-heat. The surface

Table 3. Fruit preservation with active coatings containing natural antibacterial compounds

Functional coating types	Coating material	Fruits	Effect on product	References
Potassium sorbate	Citrus pectin, rice flour	Avocado	Improved shelf-life and sensory features	32
Pomegranate peel extract and biocontrol yeast	Chitosan and locust bean gum	Oranges	Inhibition of *Penicillium digitatum*	33
Carotene proteins	Chitosan	Strawberry	Minimize the mould and yeast growth	34
Apple fibre, orange fibre, inulin and oligofructose	Sodium alginate and chitosan	Blueberries	Increase the longevity by minimizing decay by more than 50%	35

Table 4. Control physiological responses and retain physicochemical characteristics in fruits with edible coatings

Edible Coatings	Formulation	Fruit application	Key findings	References
Aloe with rosehip oil	A. arborescent or A. vera extract; with or without 2% rosehip oil	Plum ('President')	Significant reduction in respiration and ethylene production in coated fruit.	39
Chitosan	2%; 0.2% glacial acetic acid; 0.1% Tween 80	Plum ('Santa Rosa')	Climacteric peak suppressed by 14 days to 28 days in coated fruits	40
Guar gum with ginseng extract	0.15%; with or without 1% w/v ginseng extract	Sweet cherry	Firmness was found higher in coated fruits with a reduction in respiration rate	41
Gum Arabic or almond gum	10%	Sweet cherry	Firmness and titratable acidity remain constant with a reduction in ethylene production	42

temperature of the pericarp of chitosan-treated litchi fruit was lower than normal due to reduced respiration and transpiration. The temperature differential between the pericarp and the atmospheric temperature was greater than that of the uncoated fruits[37]. The rate of respiration is an important measure of the fruit's physiological state after harvest. The effect of several interventions on the rate of sweet cherry respiration during storage was investigated. The respiration rate of the control and all treatment groups exhibited a tendency of fast drop initially, stabilisation, and then gradual rise as storage time was extended. During storage, the respiration rates of the control and $CaCl_2$ treatments did not differ substantially, but both were much greater than the other treatments. From day 12 to day 30 of storage, the respiration rates of the control and treatment groups tended to remain steady, and the treatment groups' respiration rates were much lower than the control groups[38]. Retention of physio-chemical characteristics of fruits by controlling their physiological responses is one of the major roles of edible coatings (Table 4).

7. Effect of Coating on Total Soluble Solids (TSS)

Coatings exhibited a promising effect in TSS preservation in orange, considered to be one of the major sources of vitamin C. During storage studies on orange, the TSS of control and coated samples improved dramatically. There was a noticeable variation between control and coated samples in this respect, with coated samples seeing a small improvement in TSS[43]**.** Various edible coatings like Paraffin wax, Mustard oil, Aloe vera, and Turmeric paste showed significant differences in TSS was significantly affected by edible coatings. There was an increment in the TSS content in all the treatments, which may be because starch with other insoluble carbohydrates was converted into soluble solids[44]. In terms of final TSS content, paraffin wax at 50% concentration outperformed the others since it had the lowest amount of TSS, indicating the smallest increase in TSS during storage. The greatest TSS was found in treatment with control, indicating that TSS increased rapidly in storage conditions. The increase in TSS content was lowered in other treatments when compared to the control. Due to the establishment of a physical barrier for transpiration losses and a physical barrier for bacterial growth, the results indicated that 50% paraffin wax along with other edible coatings while storage reported a low level of TSS content when compared to the control[45].

In blackberries, TSS levels steadily increased as a result of water migration in the environment and fruit dehydration during storage. When compared to the untreated blackberries, the treated blackberries had stable TSS values at the end of the study. These findings showed that pectin-based edible films, particularly those containing bacteriocin, offered a protective barrier against moisture loss and, as a result, decreased fruit quality deterioration[46]. TSS increment is successfully slowed by increasing chitosan concentration owing to the reason that chitosan coatings can create a partially permeable layer around the fruit body altering the interior systems by lowering O_2 and increasing CO_2 lowering fruit metabolic and respiration activity[47].

8. Effect of Coatings on Ripening

In persimmon fruit, during storage, both treatments improved their ripening index although noncoated persimmons had a substantially greater ripening index than GA-coated fruits the increase in ripening index was significantly slowed by GA coating, especially in the second half of the storage period overall GA-treated fruits had a lower ripening index than control fruits at the end of the trial because starch is converted to simple carbohydrates and titratable acidity is lost the ripening index rises[48].

The researchers evolved an edible rice starch composite layer that substantially increased the storability of bananas at 20°C. Results showed that coating can help regulate gas transfer rates such as ambient O_2 and ethylene production, which affect fruit metabolism and maturity. Fruits with coatings retained weight, and firmness, had lower kinetics associated with digestion and demonstrated delayed development of visual markers *vis-a-vis* quality loss. According to studies, the coating had a significant impact on gas mass transfer over the skin, altering the activity of key proteins that are involved in ripening and delaying ripening in bananas[49].

9. Future Possibilities in Edible Coatings Technology

Natural goods, particularly those derived from horticulture, are gaining popularity across the world. To avoid considerable changes in freshness and to keep the nutritional and functional capabilities of diverse fruit components, consumer demand favours minimally processed items[50]. Nanotechnology now offers a promising avenue for delivering antibacterial and antioxidant compounds, vitamins, and other plant extracts such as polyphenols. Their submicron size brings up new opportunities for changing gas transport properties and natural product release, as well as improving resistance properties, opacity, usefulness, and antiseptic and antibacterial activity[51]. The addition of bioactive and functional substances in the polymeric matrix transforms the edible coatings into active systems which as result improves the safety, nutritional, and sensory qualities of coated items while also benefiting consumer health. Hence, the incorporation of active ingredients, such as antimicrobials, anti-browning agents, texture modifiers, antioxidants, nutrients, and other ingredients, in the new generation edible coatings is one of the most promising techniques for managing the quality of fresh horticultural produce[12].

Nonetheless, every mode of development includes flaws and limitations. The key problem, which requires future study, is to extend the shelf life of fresh/fresh-cut fruits without compromising their sensory and nutritional properties. Several research including creative and cost-effective edible coatings for fruits, on the other hand, are in the early stages of development and investigation before large-scale industrial implementation. The necessity that compounds have specified properties, flavours, and interactions between components that may otherwise result in alterations in the sensory profile limits the search for novel coating materials[17].

10. Conclusion

The main issue in a horticultural commodity is to prevent postharvest losses. The edible coating is a sustainable alternative to mitigate these losses without using typical plastic packaging, which is nonbiodegradable in nature and causes pollution. Functional edible coatings that can change the interior environment of fruits along with the addition in value to the food have been created and developed. These edible coatings help fresh fruits in retaining their phytochemical characteristics such as antioxidants, phenolic content, and colour, as well as physical characteristics such as respiration rate, weight loss, pH, and TSS for a longer duration of time. When compared to alternative techniques of preservation, edible coatings save money and show sustainability.

11. Consent for Publication

Not applicable.

12. Funding

None.

13. Conflict of Interest

The authors declare no conflicts of interest, financial or otherwise.

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Declared none.

15. References

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