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# Effect of chitosan based edible coating in management of post harvest losses in Papaya: A comprehensive review

Harmanjot Singh [a,1], Jasleen Kaur Bhasin [a,1], Kshirod Kumar Dash [b,*], Rafeeya Shams [a], Ayaz Mukarram shaikh [c], Kovács Béla [c,*]

[a] Department of Food Technology and Nutrition, Lovely Professional University, Phagwara, Punjab, India
[b] Department of Food Processing Technology, Ghani Khan Choudhury Institute of Engineering and Technology, Malda, West Bengal, India
[c] Faculty of Agriculture, Food Science and Environmental Management Institute of Food Science, University of Debrecen, Debrecen, 4032, Hungary

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ABSTRACT

Chitosan is a biopolymer abundantly present in the exoskeletons of crustaceans like shrimp and crabs. Chitosan is derived from chitin by a process called deacetylation, which includes demineralization, deproteinization, and deacetylation steps. Its many attributes, including biodegradability, biocompatibility, and antibacterial action, have made it extensively useful in food processing sector. Chitosan, due to its different reactive groups (primary -OH, secondary -OH, and -NH2), has been discovered to impede the growth of wide range of fungi and both gram-positive and gram-negative bacteria. This is achieved through electrostatic interactions with the cell wall, cell membrane, and cytoplasmic components of the microorganisms. Papaya is a significant tropical fruit belonging to the genus *Carica*. Post-harvest losses in papaya are high, owing to factors such as physical damage, microbial proliferation, and moisture depletion. Utilizing chitosan coating, either alone or in combination with other preservative components, has been discovered to effectively mitigate these variables, resulting in decreased post-harvest losses and enhanced papaya shelflife. The review analyzes the impact of chitosan coating on the antibacterial characteristics, quality preservation, and decrease of post-harvest losses in papaya. Applying a chitosan coating on papaya has great potential in enhancing the sustainability of papaya production and supply.

## 1. Introduction

Papaya is the fruit belonging to the sole species in the genus *Carica* of the family *Caricaceae,* which is short-lived and perennial in nature and is typically propagated from seeds (Devaki et al., 2015). It is a climacteric and tropical fruit which is known for its rich nutritional value. It may also be described as a berry-like fruit or as the "fruit of the common man" (Prajapati et al., 2017). The shape of the fruit is almost round to oval in shape, and somewhat club-shaped, which is dimensionally 15–50 cm in length, 10–20 cm in width, and weighs around 9–10 kg (Devaki et al., 2015). Today, it is widely dispersed throughout the tropical, spreading to the subtropical zone of 32° north and south latitude, which includes more than 60 countries worldwide, including India, Indonesia, Brazil, Mexico, Nigeria, Dominican Republic, United States, and Australia (Rodrigues et al., 2021; Anitha et al., 2018). Furthermore, tropical and subtropical regions of the world now harvest and consume the most fruits from this plant (Santos et al., 2014; Vij & Prashar, 2015).

The flesh of papaya is delicious and comes in a variety of colours and textures, including yellow, orange, and red. Ideally, papaya flesh contains around 0.6 % protein, 10–13 % sugar, and 85–90 % water (Prasad & Paul, 2021). It contains glucose, fructose, and sucrose, among other sugars and has comparatively low calories (32 Kcal/100 g ripe fruits), making it an optimal and favoured fruit for weight reduction (Krishna et al., 2008). Additionally, it contains abundant amount of vitamins such as vitamins A and C, riboflavin, folate, thiamine, pantothenic acid, and niacin and minerals such as calcium, iron, potassium, copper and fibres as well (Prajapati et al., 2017). Papaya is a natural source of papain, a digestive enzyme that is a common industrial ingredient in brewing, meat tenderisation, medicines, cosmetics, and beauty products (Devaki et al., 2015). It is well known for its high pectin content and can be consumed either raw or in processed forms such as jelly, candy, jam, and pickles (Prasad & Paul, 2021; Tan et al., 2020). Numerous components of the papaya plant, including the roots, leaves, peels, latex, flowers, fruits, and seeds, have nutritional and therapeutic value (Ali et al.,

* Corresponding authors.
*E-mail addresses:* kshirod@tezu.ernet.in (K.K. Dash), kovacsb@agr.unideb.hu (K. Béla).
[1] First author and second author have equal contributions.

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2012). Papaya leaf and seed extract contains a variety of phytochemicals such as flavonoids, phytosterols, carotenoids, alkaloids, phenolic compounds, and cyanogenic compounds (benzyl glucosinolate), which have been reported to provide ameliorative effects for medical conditions such as diabetes mellitus, hepatic and renal problems, fertility, hyperglycemia, amoebic dysentery, and antitumor activities (Tan et al., 2020; Archampong et al., 2019; Olcum et al., 2020; Doan et al., 2020; Singh et al., 2019; Odhong et al., 2014).

The mature papaya fruit softens quickly, gets readily infected by diseases, and is vulnerable to additional post-harvest losses, such as injury from chilling due to exposure at low temperatures (Mahmud et al., 2008). Papaya is susceptible to numerous ailments brought on by fungi, bacteria, nematodes, and viruses, which significantly reduces its productivity. Papaya anthracnose, which is caused by *Colletotrichum gloeosporioides*, is known to be the most serious of all diseases, causing significant losses to papaya fruits during transportation and storage (Prajapati et al., 2017). Due to this reason, it has a very short post-harvest shelf-life of about 7–14 days under greenhouse conditions (Marpudi et al., 2011). The percentage of wastage is greatly increased in developing countries, where the correct technologies for the storage of fruits and vegetables are lacking (FAO, 2011). The susceptibility of fresh produce to post-harvest diseases and deterioration of quality attributes increases after harvest and during prolonged storage as a result of physiological and biochemical changes in the commodities. These changes can favour the development of post-harvest pathogens and the incidence of post-harvest diseases, which are the major causes of losses through the supply chain. Therefore, the food sector places its primary focus on appropriate preservation techniques. Inadequate and costly solutions for food preservation have led scientists to create natural preservatives which are safe, effective, and acceptable (Huq et al., 2015). Keeping in mind the relatively long time storage and transportation, the use of biologically derived preservatives with compliance with health and safety regulations can bring a great solution for the preservation of the fruits (Romanazzi et al., 2018).

One such strategy that has been of recent interest is the use of edible coatings in the fresh fruit industry to reduce the deleterious effects that could take place on intact fruit tissues, which are usually subject to minimal processing. It is a novel technique for food preservation that creates physical barriers on the surface of fruits and vegetables, preventing moisture and solute movement and slowing down respiration, gas exchange, and oxidative reaction rates in order to increase the shelf-life (Arnon et al., 2014). Biopolymer coating materials are designed to transport active substances such as antibrowning agents, colourants, flavourings, nutrients, spices, and antimicrobial chemicals in order to increase product shelf life and lower the danger of pathogen growth on food surfaces (Pranoto et al., 2005). As a technology, the application of edible coatings with antifungal qualities has become popular for preserving fruits and vegetables against fungi that cause post-harvest deterioration. Studies from a variety of fields have shown that edible coatings have an antibacterial effect against *Botrytis cinerea, Colletotrichum* spp., *Penicillium* spp., and *Alternaria* spp (Wardana et al., 2021; Landi et al., 2021; Rajestary et al., 2021). Coatings can change the composition of the atmosphere surrounding the fruit, which results in creating a barrier to gas exchange, such as oxygen, carbon dioxide, and ethylene, which are involved in the respiration process. Different edible coatings have been reported to preserve the nutritional value of fruits similar to or even better than conventional packaging.

Application of chitosan treatment at the pre-harvest or post-harvest stages has been suggested to be an appropriate replacement for the usage of synthetic fungicides. By maintaining the general quality of the various fresh commodities can aid in preventing post-harvest fruit diseases and extending storage life. Chitosan (poly b-(1–4) N acetyl-d-glucosamine) has been identified as providing an ideal coating with antimicrobial properties that can induce plant defence responses when applied to vegetal tissues (Devlieghere et al., 2004). On the other hand, chitosan coating also offers a substrate for the incorporation of additional useful natural food additives, which may enhance its antibacterial capabilities and stop the quality of the fruit from degrading (Vargas et al., 2008). The United States Food and Drug Administration (USFDA) has certified chitosan as a "Generally Recognised as Safe" (GRAS) food additive; therefore, chitosan treatment in the fresh produce industry is safe for consumers and the environment (USFDA, 2013). The review analyzes the characteristics and preservation impact of chitosan-based edible coating in reducing post-harvest losses in papaya. The effects of applying chitosan coating on the antibacterial properties, and quality maintenance in papaya. The use of a chitosan coating on papaya has significant potential to improve the sustainability of papaya production and supply.

## 2. Production rate of papaya and factors influencing its production

Papaya is currently grown in more than 37 nations throughout the world, with India, Brazil, Mexico, Nigeria, Indonesia, Ethiopia, Thailand, Peru, Columbia, Guatemala, and the Philippines being the top producers (Tridge.com, 2021). These countries together accounted for approximately 68 % of papaya production worldwide (FAOSTAT, 2021). India is the world's top papaya-growing nation, having an annual production of 5989,000 t (MT) from an area covered by 138,000 hectares and a productivity of 43.40 MT/h (Anonymous, 2018). It is grown in practically all tropical and subtropical areas of India, and the top producing states are Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, and Tamil Nadu (APEDA, 2021; Prasad & Paul, 2021). Papaya is exported in the form of dried or fresh produce to various countries such as the Netherlands, Nepal, Germany, UAE, Saudi Arabia, Qatar, Kuwait, and other nations, with a total annual export profit of around 4150 lakh Indian rupees from 9996 MT of papaya export (Anonymous, 2018). The top exporting countries of papaya include Mexico, which has been reported to be the leading exporter of papaya (33.4 %) followed by Brazil (15.4 %), Guatemala (7.6 %), United States (7.6 %), and the Netherlands (7.2 %) while the United States continues to be the top importer of papaya with 37.2 % of the total import value, followed by Germany (10.1 %), Portugal (7.1 %), Canada (6.9 %), and other nations (Tridge.com, 2021).

Papaya, being a tropical plant, is highly vulnerable to frost, and its cultivation is confined to regions between 32° N and 32° S of the Equator, where the optimum temperature range for growing papayas lies between 25 °C and 30 °C (Saran & Choudhary, 2019). Exposing papaya plants to flooding for 48 h proves fatal, while even brief exposure to 0 °C can cause damage and prolonged cold spells without overhead sprinkling can result in the death of the plants (DAIS, 2009). Although mature papaya trees can endure temperatures as low as −2 °C, they are usually grown in areas where the average daily minimum temperature during mid-winter never falls below 5°

Strong, cool, hot, and dry winds are not preferred and can damage papaya plants in open and high-lying areas (Saran & Choudhary, 2019). To ensure successful plantation establishment, a shelterbelt is utilized with full sunshine, along with employing techniques like staking, earthing up for trunk support, and windbreaks to mitigate wind damage (Saran et al., 2015). Papayas thrive across a diverse range of soils, often developing a robust taproot shortly after planting. Optimal growth occurs in well-drained sandy-loam soil enriched with sufficient organic matter, which is crucial for successful cultivation (Saran & Choudhary, 2019). In regions with high rainfall and inadequate drainage, prolonged saturation can lead to plant demise, necessitating the use of raised beds and drainage ditches (Saran et al., 2015). Mulching and incorporating organic material, such as planting a cover crop like legumes, serve as valuable sources of organic matter and is implemented approximately six months before transplanting (DAIS, 2009).

Maintaining soil pH between 6.0 and 6.5 is ideal for papaya growth, and addressing deficiencies in acidic soils below pH 5.5 is achieved with calcium carbonate or lime, while sulphur is effective for correcting

deficiencies in alkaline soils above pH 8.0 (DaMatta et al., 2007). To optimize papaya orchard growth, a weed-free environment is essentially maintained which is achieved through various techniques like herbicide application, hand weeding, mulching, and deep hoeing, either individually or in combination (DaMatta et al., 2007). Inorganic materials such as plastic mulches are utilized for weed control, with plastic mulch combined with mounding identified as the most effective treatment, also aiding in preventing root rot disease (Saran et al., 2015).

Earthing up at the 4th, 6th, and 8th months post-transplanting before the monsoon season helps prevent overcrowding and waterlogging and this practice is conducted within a 30 cm radius around the plants, which promotes their upright growth in sandy-loam soils (Saran et al., 2014). Staking, using bamboo or other sticks, is implemented during the fruit development stage to protect the plant from wind damage and manage the fruit load, especially following heavy rainfall (Saran et al., 2014).

Thinning involves the removal of excess fruits, and it is done to prevent damage caused by overcrowding and reduces the risk of pressure injury and competition for space and nutrients, particularly in dwarf cultivars like Pusa Dwarf and Pusa Nanha (Saran et al., 2014, 2015). Upon the onset of flowering, retaining about 5–10 % of male plants in the orchards ensures adequate pollination, considering that hermaphrodite plants bear complete flowers (Saran et al., 2014). Employing cheesecloth, glassine paper, or wax paper bags for bagging can effectively control fruit fly infestations in small plantings (Saran & Choudhary, 2019). Cold weather conditions may disrupt pollination and lead to the shedding of unfertilized female flowers. To ensure a healthy harvest, side shoots are removed from the stem during the initial crop and prune old, dry, diseased leaves, and petioles, as these are standard practices (Saran et al., 2014). Pollarding, a technique involving the reduction of plant height, is done for one-year-old ratoon crops to mitigate vulnerability to wind damage and improve yield and productivity (Prakash et al., 2014).

## 3. Factors causing post harvest losses in papaya

Even though papaya has an immense production rate with the highest productivity among all the fruits grown in India, around 40–60 % of the total production at various papaya growing regions is wasted due to the perishable nature of papaya, leading to deterioration in quality and quantity of the product which affects the marketing as well as the income of the farmers (Prasad & Paul, 2021). As shown in Fig. 3, Post-harvest loss in papaya can be attributed to various factors, including pre-harvest factors, environmental conditions, inadequate marketing channels, improper storage and transportation, post-harvest pests and diseases, chilling injury, physiological disorders, and senescence (Prasad & Paul, 2021; Prajapati et al., 2017; Paull et al., 1997). These factors can lead to significant changes in the fruit's quality and nutritional value, as well as its appearance, texture, firmness, and flavour, which can further negatively impact the fruit's marketability and reduce its economic value (Mashau et al., 2012).

In a study conducted by Gajanana et al. (2010), papaya variety Taiwan 786, which is grown in the major papaya producing states of Andhra Pradesh and marketed in Bangalore, was studied to estimate the rate of post harvest losses, causes of these losses at different stages of handling and to study its impact on marketing efficiency. The results showed that the total post-harvest losses were calculated to be roughly 25.49 %, with field losses of 1.66 %, transit losses of 4.12 %, ripening losses of 8.22 % at the market level, and retail losses of 11.49 %. It was observed that losses in the fields were primarily brought on by immature and small-sized fruits, malformations, and harvesting damage, while bruises and pressing injuries led to transit loss at the market level. The main reasons for loss during ripening were found to be anthracnose and fruit rot caused by *alternaria* and *phytophthora*, which are two of the main post-harvest diseases which can lead to loss of quality, deeming them unfit for sale and consumption (Esguerra et al., 2020).

A similar study was conducted by Dadi et al. (2020) to assess the post-harvest losses of papaya at the wholesaler and retailer levels in Jimma Town, South Western Ethiopia. The results of the study revealed that at wholesale level, the overall loss was 21.75 %, which was further classified as 12.5 % during transportation and 9.25 % during storage, while retailers experienced a loss of approximately 15.6 % and all of these losses were attributed to factors such as inappropriate transportation, inadequate storage conditions, and a lack of suitable selling places, which often leads to fruit softening, rotting, wounding, and compactness. The study concluded that a total of 37.35 % of papaya fruits were lost across the two marketing channels in Jimma town. These results were in accordance with another study conducted by Paull et al. (1997) for examining the marketability and shelf life of papaya fruit delivered at New York terminal markets by Hawaii's packer-shippers, and they observed that the papayas were subjected to a range of disorders, including mechanical injury, over-ripeness, and parasitic diseases. Additionally, the most common causes of loss included anthracnose rot, affecting 62 % of shipments; bruise damage, affecting 22 %, and overripe fruit, affecting 48 %. Other causes of loss included soft fruit, chilling injury, and other diseases, affecting a total of 35 % of shipments inspected. According to Souza et al. (2014), papaya fruit exhibits high ethylene production when harvested at a physiologically ripe stage, owing to its increased respiratory activity, and the duration of this process may vary depending on the genotype and harvest stage. The consequent increase in ethylene production triggers alterations in the fruit's skin and pulp colour, flavour, and pulp firmness, as well as the production of volatile aromatic compounds during ripening (Galo et al., 2014). Due to their high sugar content, soft pulp, high water activity, low acidity, and rapid ripening process, papaya fruits are conducive to the establishment of pathogen-caused infections (Gonzalez-Aguilar et al., 2009; Tabassum & Khan, 2020).

## 4. Physiochemical composition of chitosan

As indicated in Table 1, the moisture content of chitosan, which is extracted from different sources, ranges from 0.0004 to 9.23 %. Commercial chitosan products consist of moisture, which is less than 10 % (Li et al., 1992). The variance in moisture content may be due to different animal species and methods used. Due to the hygroscopic nature of chitosan, the moisture content can be affected by absorption during the storage period as it has a great capacity to form hydrogen bonds with water through both its hydroxyl and amino groups (Ssekatawa et al., 2021; Khan et al., 2002). The ash content of chitosan is found to be between 0.03 and 11.77 %, and this mainly depends on the starting material and composition. According to Kumari et al., 2017, it was reported that chitosan extracted from crabs had more ash content and protein as compared to chitosan extracted from fish and shrimp sources. The ash content of a high quality grade chitosan should be less than 1 %, therefore, it acts as an indicator for checking the effectiveness of the demineralisation process of chitosan for the removal of calcium carbonate (Hossain & Iqbal, 2014). Chitosan containing high amounts of ash content may also affect its solubility, consequently contributing to lower viscosity and average molecular weight, and it can also affect other more important characteristics of the final product (Kumari et al., 2017). The protein content ranges from 1.99 to 48.55 %, and this percentage in chitosan can differ based on the source of chitin, the precursor material of chitosan and may also indicate the effectiveness of the deproteinisation process during the chitosan production (Kumari et al., 2017; Hossain & Iqbal, 2014). The fibre content in chitosan ranges from 8.74 to 55.8 %, and this difference may be due to variation in the degree of deacetylation process applied for the production of chitosan from chitin where the acetyl groups in chitin are removed using an alkaline solution resulting in a reduction in the fibre content of the material, as well as changes in other physicochemical and functional properties (Miraftab et al., 2011).

The C content, N content, and C/N ratio are important parameters in

**Table 1**
Physiochemical composition of chitosan from different source origin.

| PaParameters | Composition value | References |
|---|---|---|
| **Proximate Composition** | | |
| Moisture (wt %) | 0.0004–9.23 | Renuka et al., 2019; Kumari et al., 2017; Isa et al., 2012; Ibitoye et al., 2018; Islam et al., 2022; Hossain & Iqbal, 2014; Ushakumari & Ramanujan, 2012 |
| Ash (wt%) | 0.03–11.77 | Renuka et al., 2019; Kumari et al., 2017; Isa et al., 2012; Puvvada et al., 2012; Hossain & Iqbal, 2014; Ssekatawa et al., 2021 |
| Protein (wt%) | 1.99–48.55 | Renuka et al., 2019; Kumari et al., 2017; Isa et al., 2012; Rout, 2001 |
| Fibre (wt%) | 8.74–55.8 | Isa et al., 2012; Miraftab et al., 2011, Rout, 2001 |
| **Ultimate Composition** | | |
| C (wt%) | 16.23–40.97 | Isa et al., 2012; Ibitoye et al., 2018; Islam et al., 2022 |
| H (wt%) | 6.51 | Islam et al., 2022 |
| O (wt%) | 34.86 | Islam et al., 2022 |
| N (wt%) | 2.71–8.50 | Isa et al., 2012; Ibitoye et al., 2018; Ssekatawa et al., 2021; Islam et al., 2022; Rout, 2001 |
| C/N (molar ratio) | 5.23–7.79 | Isa et al., 2012; Ibitoye et al., 2018; Kumari et al., 2017; Islam et al., 2022 |
| **Techno-functional Properties** | | |
| pH | 7.9–8.5 | Renuka et al., 2019; Divya et al., 2014; Puvvada et al., 2012 |
| Molecular Weight (KDa) | 110.64–1200 | Renuka et al., 2019; Ssekatawa et al., 2021; Puvvada et al., 2012; Struszczyk et al., 2002 |
| Solubility (%) | 48.30–98.40 | Renuka et al., 2019; Kumari et al., 2017; Ssekatawa et al., 2021; Hossain & Iqbal, 2014 |
| Water Binding Capacity (%) | 138.0–1150.0 | Renuka et al., 2019; Kumari et al., 2017; Hossain & Iqbal, 2014; Rout, 2001; Knorr, 1982 |
| Fat Binding Capacity (%) | 104.0–331.28 | Renuka et al., 2019; Kumari et al., 2017; Hossain & Iqbal, 2014; Rout, 2001; Knorr, 1982 |

the characterisation of chitosan, as they provide information about the chemical composition and structure of the material. The C content in chitosan indicates the level of carbon in the material, which is a key component of the glucosamine units that make up chitosan (Islam et al., 2022). According to Ibitoye et al. (2018), the C content in chitosan was found to be around 40.97 % in commercial shrimp and 38.98 % in house crickets. Similarly, Kumari et al. (2017) reported the C content in chitosan synthesised from fish scales, crab, and shrimp shells to be in the range of 34.89 - 48.60 %. The N content, on the other hand, refers to the level of nitrogen present in the material, which indicates the level of purity in chitosan and also points out the effectiveness of the deproteinisation process (Ibitoye et al., 2018). A lower amount of nitrogen signifies the minimum residual protein remaining in chitosan (Majtán et al. 2007; Ivshina et al. 2009). Ssekatawa et al. (2021) reported the N content in chitosan extracted from Nile perch scales to be 7.0 %, while the N content in chitosan extracted from banana weevils was found to be 6.9 %. Ibitoye et al. (2018) reported the N content in chitosan extracted from house crickets to be 5.932 %, while the N content in chitosan extracted from commercial shrimps was found to be 6.182 %. The C/N ratio in chitosan provides information about the degree of deacetylation, which is an important parameter that affects various properties of chitosan (Isa et al., 2012). A low C/N ratio indicates the presence of impurities in the derived chitosan (Yen et al., 2009). According to Kumari et al. (2017), the C/N ratio of chitosan derived from fish scales, shrimp and crab was found to be 7.62 %, 7.79 % and 6.20 %, respectively. Similarly, Ibitoye et al. (2018) reported that the C/N ratio in chitosan extracted from house cricket was found to be 6.571 %, while the C/N ratio in chitosan extracted from commercial shrimps was found to be 6.63 %. Ssekatawa et al. (2021) also reported the C/N ratio in chitosan extracted from Ugandan edible mushrooms to be in the range of 5.92–6.80 %.

One of the most significant physiochemical features of chitosan is its molecular weight, which influences a variety of physicochemical and biological behaviours, including mucoadhesion, hydrophilicity, viscosity, moisture absorption, biodegradability, and antibacterial activity (Aranaz et al., 2009). According to Struszczyk et al. (2002), the average molecular weight of commercial chitosan ranges from 100 kDa to 1200 kDa. This is in accordance with the results obtained by Renuka et al. (2019), who reported that the average molecular weight of chitosan determined by using intrinsic viscosity was 110.64 kDa. Similarly, Ssekatawa et al. (2021) found that the average molecular weight ranged from 291 kDa for Nile perch scales chitosan to 348 kDa for mushroom chitosan. The process of deacetylation may lead to the lower molecular weight of chitosan (Szymańskav & Winnicka, 2015), which has a greater ability to penetrate bacterial cell walls compared to high molecular weight chitosan. As a result, it can effectively infiltrate the cell and interact with the DNA, leading to the inhibition of the transcription process and subsequently disrupting protein synthesis. Thus, low molecular weight chitosan possesses potent antimicrobial activity. (Yilmaz, 2020; Sudarshan et al., 1992). In contrast, high molecular weight chitosan can exhibit antibacterial activity at higher concentrations by binding to negatively charged bacterial cell wall components through electrostatic interactions, thereby creating an impermeable coating around the cell, which restricts the movement of materials into and out of the cell. On the other hand, chitosan with a moderate molecular weight has been demonstrated to possess superior anti-cholesterol activity when compared to chitosan with a higher molecular weight (Kara & Stevens, 2002).

The solubility of chitosan ranges from 48.30 to 98.40 % and is a crucial parameter for assessing its quality. The degree of deacetylation, which directly impacts the solubility of chitosan, is a key determinant of its overall quality (Samar et al., 2015). Kumari et al. (2017) reported that the solubility of fish chitosan was higher (78 %) than crab (60 %) and shrimp chitosan (70 %). On the other hand, Hossain and Iqbal (2014) discovered that the solubility of chitosan ranged from 48.3 to 97.65 %, and this variation was due to the influence of various critical factors such as temperature and deacetylation reaction time, alkali concentration, the ratio of chitin to alkali solution, as well as particle size. The solubility of chitosan is dependent upon the removal of the acetyl group during the deacetylation process, and a lower degree of deacetylation may have an unfavourable impact on the outcomes (No et al., 2003).

The fat binding capacity (FBC) and water binding capacity (WBC) of chitosan are important functional properties that can affect its potential applications. Renuka et al. (2019) reported that chitosan extracted from *Parapeneopsis stylifera* shrimp shells had a FBC of 331.28 % and a WBC of 637.33 %. The authors attributed these properties to the degree of deacetylation of chitosan and its molecular weight. Similarly, Kumari et al. (2017) synthesised chitosan from fish scales, crab, and shrimp shells and found that the FBC and WBC were influenced by the source of chitosan. Shrimp shell chitosan had the highest FBC and WBC values among the three sources tested. Hossain and Iqbal (2014) observed that the FBC and WBC of chitosan were found to be 427.98 % and 537.29 %. The fat binding capacity (FBC) of chitosan is affected by factors such as the crystallinity and presence of salt-forming groups and residual protein. Additionally, the FBC may be influenced by the viscosity of chitosan, with lower viscosity leading to lower FBC (Rout, 2001; Knorr, 1982). These findings have been reported in previous studies, with Rout (2001) highlighting that FBC and WBC were influenced by reversing the sequence of steps such as demineralisation and deproteinisation.

## 5. Method of extraction of chitosan

A large number of edible coatings are available, and among them, chitosan is the most common.

Chitosan (β- (1,4)−2-amino-2-deoxy-d-glucose) is a natural biopolymer obtained by deacetylation of chitin, which is the second most important polysaccharide in nature after cellulose and is present in the exoskeleton structure of marine invertebrates, insects, as well as fungi, algae, and yeast (Neto et al., 2022; Gao et al., 2022).

The traditional process of extracting chitosan involves three main stages, namely demineralisation, deproteinisation, and deacetylation (Knidri et al., 2018). The extraction of Chitosan from Crustaceans is presented in Fig. 1. Demineralisation is carried out in dilute hydrochloric acid to remove calcium carbonate and calcium chloride, which are the primary inorganic components of crustacean exoskeletons. The resulting material is then washed, filtered, and dried overnight. The release of carbon dioxide ($CO_2$) during the demineralisation process serves as a reliable indicator of the amount of mineral content and the level of interaction between the acid and mineral matter, which is influenced by the type of species being utilised (Kumari et al., 2015). Deproteinisation involves treating the material with dilute sodium hydroxide to remove proteins, and complete deproteinisation can be confirmed by the absence of any colour in the solution when left undisturbed overnight (Kumari et al., 2015). This is followed by washing with distilled water to neutralise chitin and drying it in the oven at around 110 °C. The resulting purified chitin can be used as an excellent source of animal feed (Benhabiles et al., 2013). Deacetylation involves the removal of the acetyl group to convert chitin to chitosan, which is achieved by treating the material with concentrated sodium or potassium hydroxide at high temperatures. From a chemical perspective, both acids and alkalis are viable options for deacetylating chitin, however, due to the high susceptibility of glycosidic bonds to acid, alkali deacetylation is more commonly employed (Hajji et al., 2014). Chitosan can be extracted from chitin using either heterogeneous or homogeneous approach. In the heterogeneous approach, chitin is typically subjected to treatment with a concentrated hot solution of NaOH for several hours. As a result, chitosan is produced as an insoluble residue with deacetylation levels ranging from approximately 85 % to 99 %. On the other hand, the homogeneous method involves preparing alkali chitin by dispersing chitin in concentrated NaOH solution at room temperature

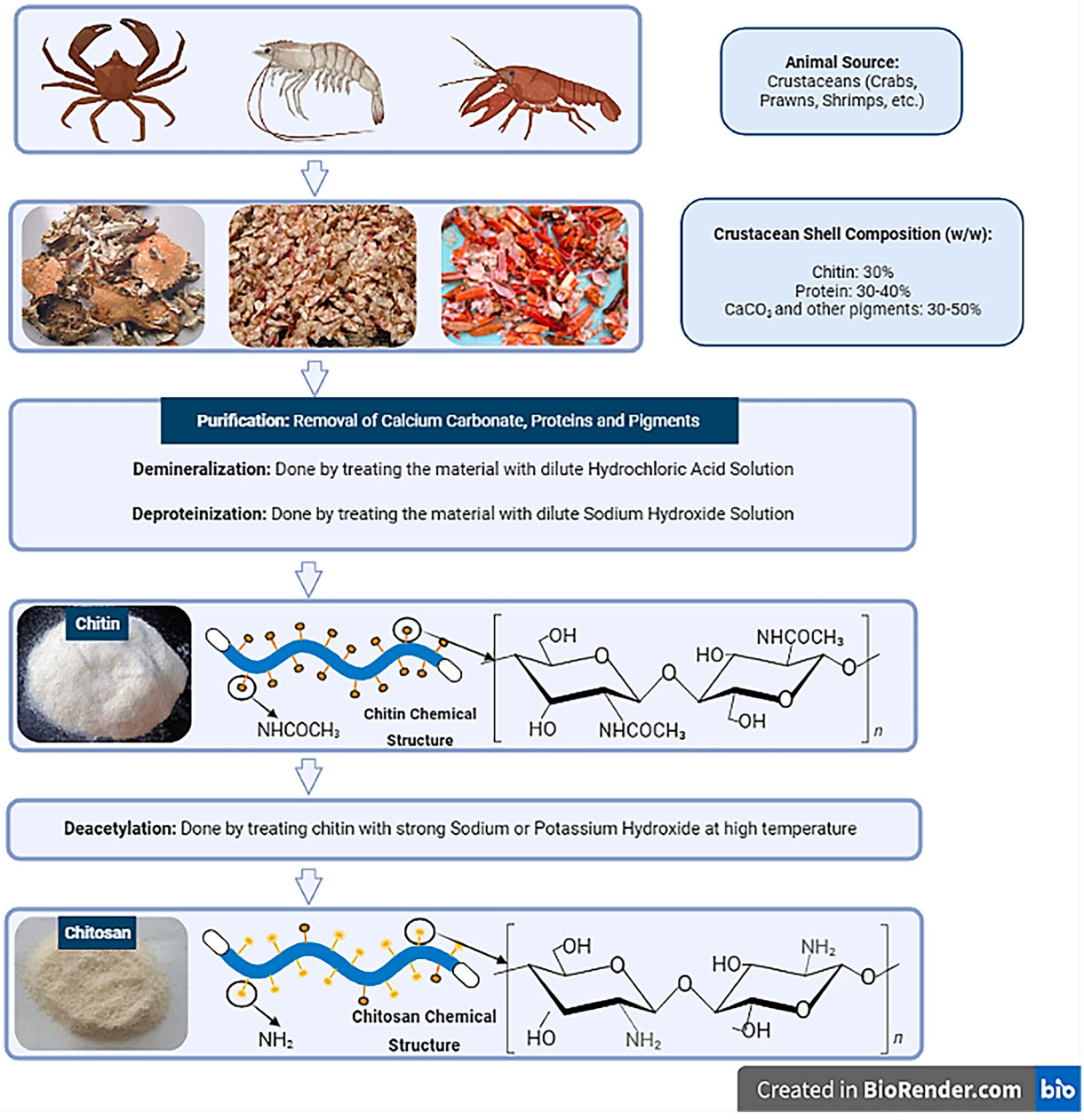


**Fig. 1.** Extraction of Chitosan from Crustaceans.

for at least three hours, followed by dissolution in crushed ice at around 0 °C. This method yields soluble chitosan with an average degree of acetylation ranging from 48 % to 55 % (Hajji et al., 2014). According to Kurita (2006), the deacetylation process of chitin can be significantly expedited by immersing it in a concentrated solution of sodium hydroxide at room temperature before applying heat. Following the reaction, the resulting material is subjected to multiple washes with distilled water until it reaches a neutral pH level, and then it is dried overnight in an oven. Several factors involved in the deacetylation process can influence the characteristics of the resulting chitosan (Li et al., 1992). Rege and Block (1999) investigated the impact of temperature, processing duration, and mechanical shear on chitosan properties, highlighting that temperature and processing duration notably affect the degree of deacetylation (DA) and molecular weight (MW). Another study conducted by Tolaimate et al. (2000) emphasized the significant influence of temperature and the repetition of alkaline steps on chitosan DA. These studies, conducted using a traditional one-variable-at-a-time approach, collectively suggest that chitosan MW and DA are primarily influenced by NaOH concentration, reaction time, temperature, and the repetition of alkaline steps.

Even though the chemical extraction method of chitosan is the most widely used method available due to its low cost and suitability to mass production, this extraction method has several drawbacks, including, contamination of wastewater with chemical residues, and increased purification costs (Younes & Rinaudo, 2015). The growing focus on environmentally friendly extraction techniques, guided by principles of green chemistry, has led to increased interest in using enzymes and microorganisms for chitosan extraction. Enzymatic extraction methods offer advantages such as high reproducibility, shorter processing times, simpler handling, reduced solvent usage, and lower energy requirements. Chitin deacetylase is an enzyme extracted from various fungi (Araki & Ito, 1975; Martinou et al., 1993; Gao et al., 1995; Alfonso et al., 1995) and insect species (Sundara et al., 1982), and this enyme facilitates the breakdown of N-acetamido bonds within chitin, resulting in the formation of chitosan. However, in a study conducted by Martinou et al. (1995), the efficacy of chitin deacetylase isolated from the fungus *M. rouxii*, in chitosan production was evaluated by using chitin as a substrate in both its crystalline and amorphous states, and it was reported that the deacetylation levels remained notably low (<10 %), suggesting that the enzyme exhibits limited effectiveness on insoluble chitins. Therefore, it's worth noting that enzymatic extraction methods are currently limited to laboratory-scale studies.

## 6. Properties and importance of chitosan as an edible coating

The major property of chitosan is dictated by the presence of three different functional groups (primary —OH, secondary —OH and —$NH_2$) and its water solubility in acidic pH. Due to the presence of reactive groups, it inhibits the growth of a wide variety of bacteria and fungi (Hosseinnejad & Jafari, 2016). Chitosan has a wide range of uses and can be used to create different formulations (Fatehi et al., 2010). To increase the security, functionality, and quality of fruits and vegetables, chitosan-based edible coatings can also be utilised as transporters of food ingredients such as antimicrobials, texture enhancers, and nutraceuticals. It is one of the most used edible coatings due to its biocompatibility, biodegradability, and bioactivity since it is a powerful material that can be applied in human medicine, cosmetics, and agriculture. Chitosan can induce host defences, exhibit antibacterial activity towards fungi that cause decay, and create a semi-permeable layer on a treated surface when applied to fruits and vegetables (Romanazzi et al., 2018). This edible coating has been used extensively to preserve fresh fruits and vegetables after harvest.

In recent years, there has been a rise in the scientific literature discussing chitosan-based edible coatings. This can be explained by the significance of chitosan in plant protection as a natural fungicide and plant-defence enhancer, as well as by the fact that it is used all over the world to extend the shelf life of a variety of fruits and vegetables. By changing the permeability of $O_2$ intake and $CO_2$ production, this biopolymer can create a semipermeable layer on the surfaces of fruits and vegetables, which lowers respiration rates and boosts antioxidant activity (Shah & Hashmi, 2020). Chitosan has demonstrated inhibitory effects on a variety of post-harvest fungal infections and exhibits broad-spectrum antibacterial activities (Rajestary et al., 2021). In a study by Novita et al. (2012), it was shown that chitosan has excellent fungicidal qualities and can be used to extend the shelf life of tomatoes. It can operate as an exogenous elicitor inducing activity of many defence-related enzymes in papaya fruit, as demonstrated by Landi et al. (2021). Additionally, Hamdayanty et al. (2012) discovered that chitosan coating with a concentration of 0.75 % was efficient in reducing disease infestation and the severity of damage, as well as inhibiting fruit ripening in papayas over a period of six days.

## 7. Challenges associated with the use of chitosan in food preservation

Even though chitosan can be extensively utilized for preserving various food products due to its distinctive properties, its application in the food sector is significantly restricted by its poor solubility and inadequate mechanical strength (Yadav et al., 2023). Nonetheless, solubility can be enhanced through various modifications, resulting in new derivatives with better physicochemical properties and a broader range of applications.

Another challenge associated with chitosan application in food preservation was studied by Hu and Gänzle, (2018), where the authors observed that the effectiveness of chitosan in reducing microbial cell counts is limited to a 2.5 log (CFU per g) decrease, regardless of the food matrix or the method of application. This statement is supported by the findings of Leleu et al. (2011), who demonstrated that coating eggs with a 2 % chitosan solution did not prove lethal to *Salmonella Enteritidis*, however, when the chitosan solution was applied to eggshells and dried before bacterial inoculation, it provided a protective barrier that reduced *Salmonella* penetration. Similar results were obtained by Moradi et al. (2011) where the authors reported that chitosan films were not bactericidal but inhibited the growth of L. *monocytogenes* on ready-to-eat sausage slices. However, in contrast to these studies, a study conducted by Anacarso et al. (2011) reported a reduction of over 5 log (CFU per g) of *Listeria monocytogenes* on apples and grapes treated with a 2 % (w/v) chitosan solution. This significant antilisterial effect is likely due to the smooth surfaces of the fruits, which create a high local concentration of chitosan and promote strong interactions between the bacterial cells and chitosan (Hu & Gänzle, 2018). According to Hu and Gänzle (2018), food components such as NaCl, proteins, and starch can negatively impact chitosan's effectiveness by neutralizing its positive charge, therefore, chitosan's ability to inactivate pathogens in food is generally restricted to a reduction of 1–2 log (CFU per g), posing a significant challenge for its use as a broad-spectrum food preservative.

## 8. Mechanism of preservative action of chitosan against bacteria

Chitosan is a cationic biopolymer with antibacterial characteristics that are influenced by various factors such as pH, concentration, molecular weight, degree of polymerisation, and cross-linking (Elsabee & Abdou, 2013). Chitosan solution is highly stable over a long period of time; however, its stability in neutral pH is highly important for exhibiting antimicrobial activity against a wide variety of foodborne pathogens (Alishahi & Aïder, 2012). Electrostatic interactions with the bacterial cell wall, cell membrane, and cytoplasmic components are the main modes of action for antibacterial activity.

Chitosan has been found to be effective against both gram-positive and gram-negative bacteria. Gram-negative bacteria like *Escherichia coli* have an asymmetric lipid-protein bilayer (lipopolysaccharide, LPS) that makes up their outer membrane (OM). The divalent cations ($Ca^{2+}$

and $Mg^{2+}$) in the outer membrane have a crucial role in maintaining the stability of the LPS molecules' core anionic charges (Khan et al., 2015). It can be hypothesised that chitosan replaces the divalent cations from their binding sites and reduces the interaction between the LPS molecules, causing membrane disruption and cell lysis due to penetration (through electrostatic interaction) of positively charged chitosan through the cell membrane of gram-negative bacteria. Unlike gram-negative bacteria, the gram-positive bacteria do not have an outer membrane. Hence, chitosan, as a polycationic long-chain molecule, can adhere better with gram-positive bacterial members such as *Staphylococcus aureus*. Due to this reason, gram-positive bacteria are more effectively inhibited by chitosan than gram-negative bacteria. According to the literature, gram-positive bacteria contain poly-anionic surface polymers such as teichoic acid and lipoteichoic acid, which interact with internal molecules to impair critical bacterial functions and activities (Aranda-Martinez et al., 2016). Raafat et al. (2008) reported simultaneous permeation of the cell membrane to small cellular components, coupled to a significant membrane depolarisation. No concomitant cell wall biosynthesis was observed. Later, they analysed multiple changes in the expression profile of S. aureus SG11 genes, which are involved with the regulation of stress and autolysis and the genes involved with energy metabolism and postulated a possible mechanism for chitosan's activity. According to Chung and Chen (2008), the removal ratios of chitosan for S. aureus protoplasts and E. coli spheroplasts were significantly higher than those for intact cells during the first 3–4 h of contact time, indicating chitosan-cell wall interaction is more intense than other cell membranes.

In another study, chitosan in gel form was used in the antibacterial tests carried out by turbidity and well inhibition zone, showing chitosan consistently more active against the gram-positive *S. aureus* than gram-negative E. coli (Goy et al., 2016). Morimoto et al. (2001) reported that chitosan derivatives have better specific binding activity on the cell wall of Pseudomonas aerogenosa. Lal et al. (2013) reported the interaction of chitosan with cell surface polymers such as teichoic acid of gram-positive bacteria, which is consistent with the fact that binding of chitosan with the lipopolysaccharide layer of a gram-negative bacteria cell wall would not significantly affect the susceptibility. However, adherence due to electrostatic interaction may cause secondary effects on the cytoplasmic membrane, such as disruption of the cell membrane, which finally results in leakage of small cellular components. The similarity between the antibacterial profiles and patterns of chitosan and those of two other control substances, polymyxin and ethylene diamine tetraacetic acid (EDTA), verified the amino group assisted mechanism of chitosan. Helander et al. (2001) detailed the specific binding mechanism of chitosan on gram-negative bacteria that relates weakening of the barrier function of the outer membrane. Chemical and electrophoretic analyses of free cell supernatants of chitosan-treated cell suspensions showed that the interaction of chitosan with *E. coli* and *S. typhimurioum* involved no release of the LPS or other membrane lipids. This was further evidenced by using highly cationic mutants of S. typhimurioum, which was more resistant to chitosan than parent strains. In the same study, they found chitosan caused extensive cell surface alterations and covered the outer membrane with vesicular structures, as shown in their electron microscopy study (Helander et al., 2001). The activity of

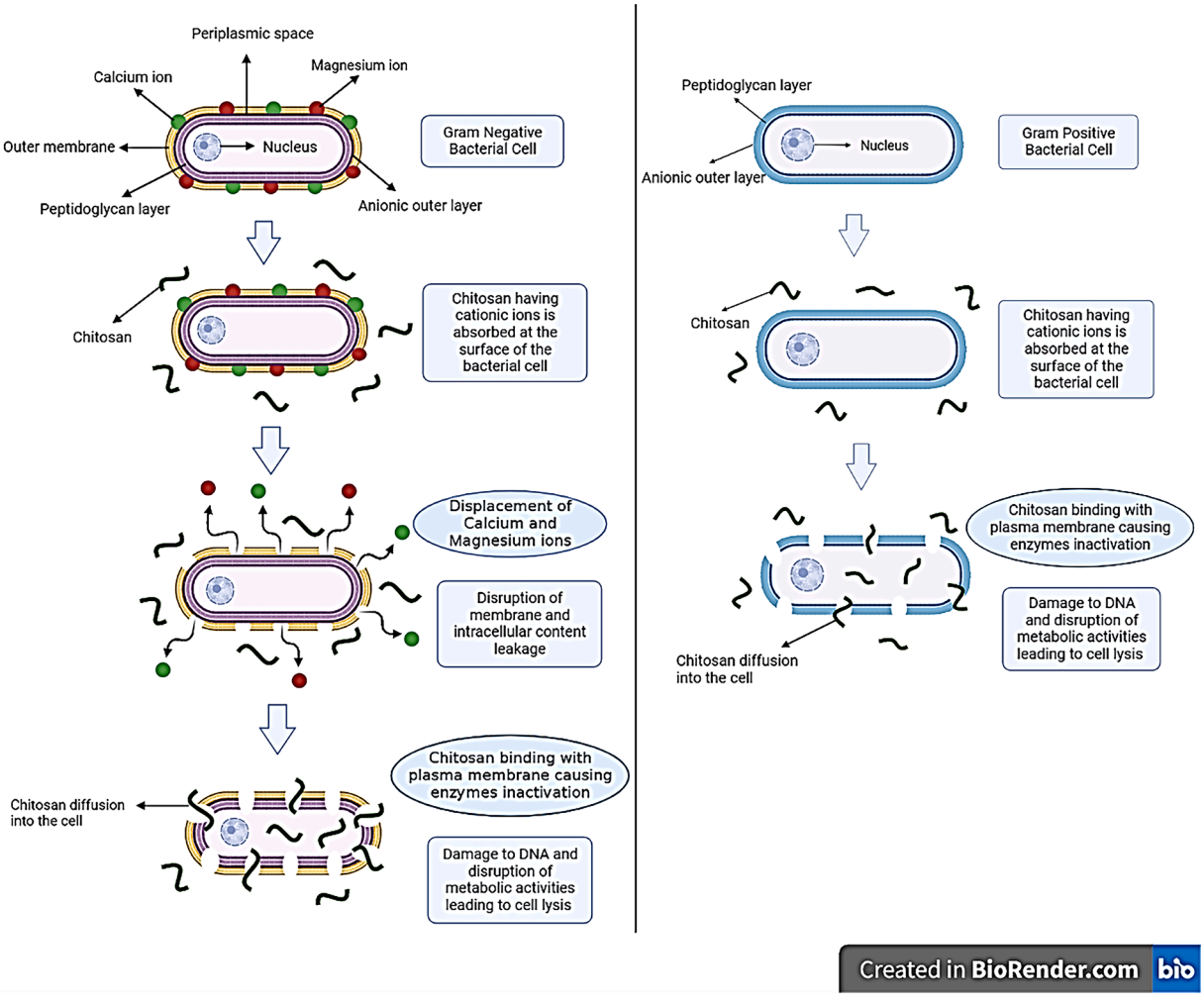


**Fig. 2.** Antibacterial activity of chitosan against gram-negative (left) and gram positive (right) bacteria.

chitosan on gram-positive and gram-negative bacteria was again evidenced and established that chitosan in acid pH is extensively protonated and bound with carboxyl and phosphate groups of the bacterial surface, which offers potential sites for electrostatic binding of chitosan (Li et al., 2016). It should be noted that chitosan shows broad spectrum activity on microorganisms except the fungi, which contain chitosan as a wall constituent. Chitosan's antimicrobial activity (as a preservative) is often limited to food, such as fruit and vegetable products with low protein and NaCl content (Roller & Covill, 1999). The antibacterial activity of chitosan against gram-negative (left) and gram positive (right) bacteria is presented in Fig. 2.

## 9. Preservative effect of chitosan edible coating on shelf life of papaya

The utilisation of chitosan in the preservation of perishable fruits such as papaya is extensively explored in the form of edible coating, which refers to the application of a thin film directly onto the surface of the targeted product to provide protection (Duan et al., 2019). Edible coatings or films serve as a protective barrier surrounding fruits and vegetables, which are also safe for consumption along with the coated product (Kerch, 2015). Table 2 shows various studies which have investigated the effect of chitosan based edible coating alone or in combination with other added values in managing the post harvest losses in papaya and increasing its shelf life while retaining its sensory attributes for a longer time.

A study conducted by Dotto et al., 2015 investigated the effect of chitosan solution on the microbiological shelf life extension of papaya. The researchers coated papaya fruit samples using chitosan solutions having different molecular weights (150 kDa and 300 kDa) and stored them for 20 days under ambient conditions. It was observed that the application of chitosan solutions (150 kDa and 300 kDa) on papaya fruits resulted in decreased levels of mesophilic bacteria and yeasts/-moulds compared to untreated fruits, especially after 5 and 7 days of storage, respectively. Similar observations were reported by Escamilla-García et al. (2018), where researchers coated the papaya sample with chitosan and oxidised starch and observed that the logarithmic values of the total coliforms, yeasts, mesophilic bacteria, and fungi were significantly higher in the uncoated papaya samples compared to the coated ones. Additionally, the growth rate of these microorganisms was observed to be slower in the coated papaya samples compared to the uncoated ones. This indicates that chitosan solution possesses antibacterial and antifungal properties when used on papaya fruits, which are believed to be due to the cationic properties of chitosan, which can affect the composition and permeability of microorganisms' cell membranes (Bautista-Baños et al., 2013). Chitosan's antimicrobial effects can also be attributed to its ability to reduce the respiratory activity and activity of certain enzymes in microorganisms (Aquino et al., 2015).

Another study by Vilaplana et al. (2019) evaluated the impact of chitosan post-harvest dip treatment (different concentrations ranging

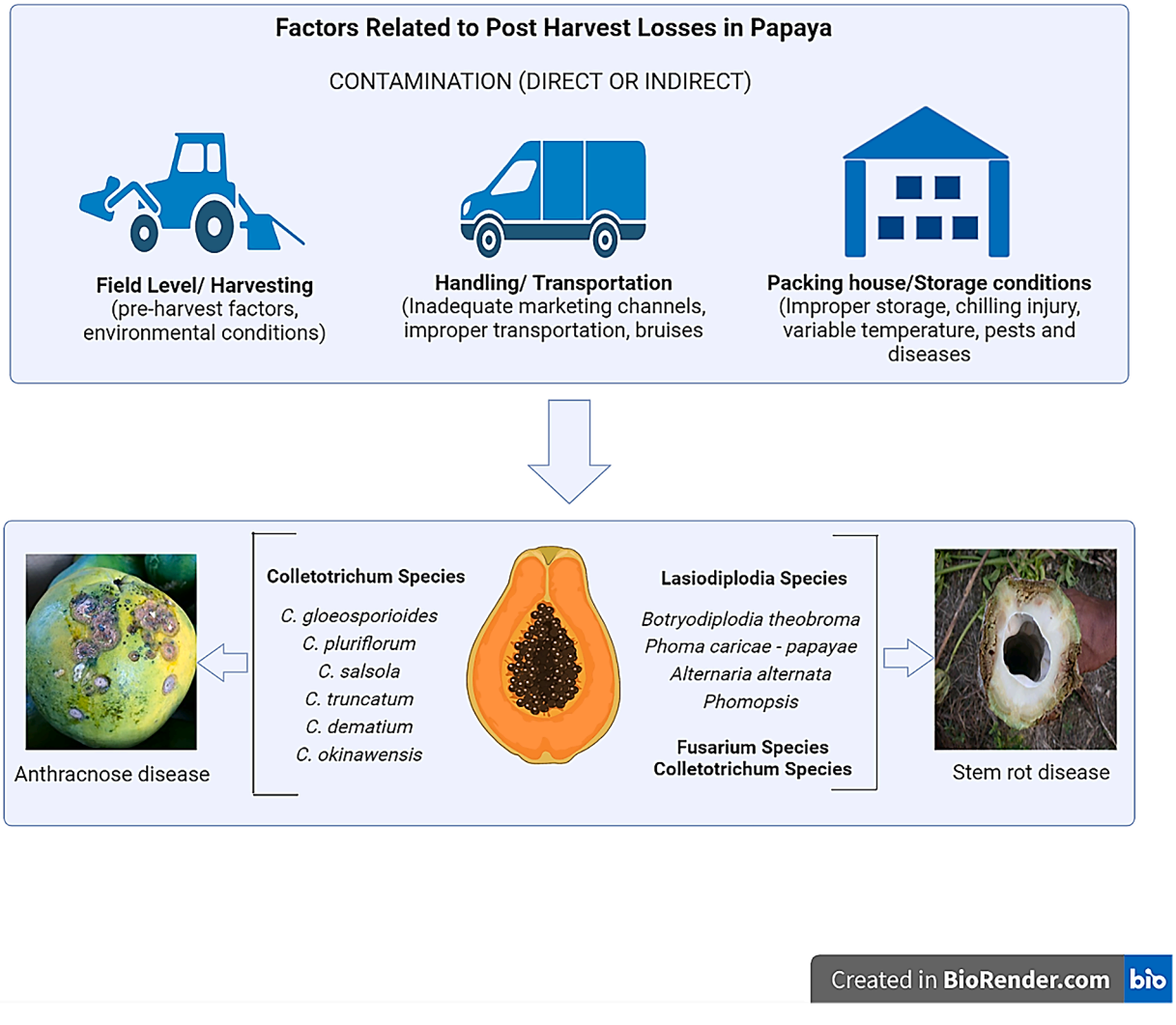


**Fig. 3.** Factors leading to post-harvest losses in papaya.

**Table 2**
Studies on effect of chitosan edible coating in management of post-harvest losses in papaya.

| Coating Formulations Used | Papaya Form | Storage Conditions | Added Value | Effects and Potential Findings | References |
|---|---|---|---|---|---|
| T1: Chitosan Coating: 0.75 % (w/v), T2: Beeswax Coating: 6 % (w/v), T3: Control | Whole papaya fruit | Stored at room temperature (25–27 °C) till maturity stage six | Beeswax emulsion | • Keeping quality of papaya significantly increased when coating prepared with chitosan (11.33 days after harvest) and beeswax (12.33 days after harvest) was applied as compared to the untreated control group (7.67 days after harvest).<br>• Papaya fruits that were coated with chitosan experienced delayed maturity until stage six, resulting in an extended shelf life, likely attributed to reduced rates of respiration and transpiration.<br>• Chitosan coated fruit had lower weight loss (6.76 %) as compared to the control group (8.54 %) and maintained the hardness and TSS values of papaya.<br>• Papaya coated with chitosan had a better and smooth appearance and were free from fungi due to the antimicrobial properties of chitosan, which effectively inhibits the growth of spoilage microorganisms. | Mukdisari et al., 2016 |
| T1: Control (distilled water); T2: AsA: 1.5 % (w/v) ascorbic acid; T3: CTS: 1.0 % (w/v) chitosan; T4: AsA + CTS: 1.5 % (w/v) ascorbic acid + 1.0 % (w/v) chitosan | Green and mature whole papaya fruit | Stored at 20 °C and 80 –90 % relative humidity for 0, 4, 8, 12, and 16 days | Ascorbic acid | • Chitosan and ascorbic acid (AsA + CTS) combined coating significantly reduced weight loss (21.12–25.29 %) and increased firmness (64.32–619.16 %) during the storage of papaya as compared to control.<br>• Decreased L*, *a** and *b** values were observed with the application of AsA + CTS coating, which indicated delayed fruit senescence and browning<br>• Application of AsA + CTS increased the pH of papaya fruits by 4.36 –11.73 %, reduced TSS (3.45 - 4.90 %) and increased TA (12.70 - 15.80 %) as compared to CTS.<br>• AsA + CTS treatments significantly decreased the ripening index by 19.15 - 34.00 % as compared to control.<br>• Reducing sugar content decreased (5.23 –13.79 %) and soluble sugar content increased (4.06 - 4.81 %) with AsA + CTS treatments during the storage days as compared to the control<br>• AsA + CTS treatment significantly reduced $H_2O_2$ content (26.23–66.26 %) and MDA levels (28.06–43.36 %) at all storage dates as compared to control<br>• Inhibition of softening enzyme activity and gene expression level of cell wall degrading enzymes such as CX, PG, PME, and β-GAL. | Zhou et al., 2022 |
| T1- Control<br>T2- Chitosan (1% w/v) + tuna fish gelatin solution;<br>T3- chitosan (1% w/v) + tuna fish gelatin solution + black tea extract (5% w/v);<br>T4- chitosan (1% w/v) + tuna fish gelatin solution + black tea extract (10% w/v);<br>T5- chitosan (1% w/v) + tuna fish gelatin solution + black tea extract (15% w/v) | Minimally processed papaya fruit | Storage durations (1, 4, 7, and 10 days) | Tuna skin gelatin and black tea extract | • The decrease in hardness occurred very quickly during the storage period in T1 sample (0.35 Nm on day 1 and 0.13 Nm on day 10) as compared to the T3 sample (0.19 Nm on day 1 and 0.14 Nm on day 10).<br>• The lowest weight loss was observed in T5 samples (1.91–4.61 %) as compared to T1 samples (1.88–6.02 %) due to the presence of gelatin and chitosan-based coatings, which act as a barrier to water vapor in minimally processed fruits, reducing the mass loss during storage.<br>• The increase in TSS content in T5 fruit samples was higher (8.83 $^{O}$Brix) as compared to T1 (8.33 $^{O}$Brix) and this could be due to the influence of edible coating layer dissolving during the test.<br>• The antioxidant activity was found to be slightly higher in T5 samples (59.26–72.62 %) as compared to T1 samples (66.97–72 %) and this may due to presence of tea polyphenols and chitosan as both have strong antioxidant properties especially in terms of the ability to scavenge hydroxyl radicals and reactive oxygen species. | Sekarina et al., 2023 |

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**Table 2** (*continued*)

| Coating Formulations Used | Papaya Form | Storage Conditions | Added Value | Effects and Potential Findings | References |
|---|---|---|---|---|---|
| | | | | • Microbial growth in control sample was faster (7.38 cfu/ml) than in the edible coating treatment sample with the addition of black tea extract (6.97–7.42 cfu/ml) and this may be due to presence of tea polyphenols and chitosan, which can interact with negatively charged residues on the surface of microbial cells by an electrostatic attraction so that it flocculates and absorbs on the surface of microorganisms, then inhibits the physiological metabolism of microorganisms and finally inhibits the growth of microorganisms. | |
| T1- Control;T2- Chitosan coating (5 g/L) after treatment with hot water;T3- Chitosan coating (10 g/L) after treatment with hot water;T4- Chitosan coating (15 g/L) after treatment with hot water;<br>T5- Chitosan coating (20 g/L) after treatment with hot water | Whole papaya fruit | Stored for 28 days at 10 °C + 7 days of shelf-life at 20 °C (35 days) | Hot Water Treatment | • Gradual increase in chitosan concentration in the coating showed better preserving capabilities.<br>• Weight loss in highest concentration of chitosan (T5) was around 5.2 % whereas in the case of control (T1) it was around 8.4 % hence showing a significant rate of decrease in weight loss as the concentration of coating increases.<br>• Hue angle and colour tests indicate that chitosan coating has a better effect on retaining colour of papaya as hue angles loss was observed to be lower in (T5) as compared to (T1)<br>• Loss of firmness and textural loss was observed to be less in (T5) as it had the highest concentration of chitosan.<br>• Increase in Total soluble solids value (TSS) in control at 28 days was observed. In the case of T5 the increase percent was lower at 28days which indicates delayed ripening. Hence increasing the desirability. | Vilaplana et al., 2019 |
| T1- Control;<br>T2- Chitosan coating layer: 0.5 % chitosan solution(w/v);<br>T3- Pullulan coating layer: 0.5 % pullulan solution (w/v);<br>T4- Two layer coating: 0.5 % pullulan solution (w/v) + 0.5 % chitosan solution (w/v);<br>T5- Four layer coating: 0.5 % pullulan solution (w/v) + 0.5 % chitosan solution (w/v);<br>T6- Six layer coating by 0.5 % pullulan solution (w/v) + 0.5 % chitosan solution (w/v) | Whole and fresh papaya fruits | Stored at 25 °C, 50 % relative humidity up to 14 days | Pullulan coating | • Weight loss in control was observed to be 28.86 % at 14th day whereas for two layers, four layers and six layers coating, the percentage was 15.53 %, 10.41 % and 13.85 % respectively. Hence 4 layer coating showed the best results in preventing weight loss.<br>• Loss of firmness was observed in control papaya as it got completely softened at 14th day. 4 layer papaya gave the best results in fruit firmness meter which was 20.2 N whereas for 5 layer and 6 layer coating it was 15.6 N and 16.9 N respectively.<br>• Colour being the indicator which represents maturity of papaya was analysed using b* value of spectrophotometer and the control showed highest value at 14th day (51.8) on the other hand 4 layer coating (T5) showed the lowest value (37.6) which ensured the delaying of undesired ripening.<br>• Anti-bacterial properties of chitosan decreased the respiratory rate in which the 4 layer coating was the most stable one.<br>• Vitamin-C content showed a significant decrease in control papaya (15.06 mg/kg) and it was highest in 4 layer coated papaya (26.17 mg/kg). | Zhang et al., 2019 |
| T1- Control;T2- Chitosan coating (molecular weight: 150 kDa);<br>T3- Chitosan coating (molecular weight: 300 kDa) | Whole papaya fruits | Stored at ambient temperature (18 - 24 °C) with air relative humidity ranging from 60 to 80 % for 20 days | - | • Chitosan (150 kDa) showed higher moisture content in storage condition (8.5 ± 0.3 %) as compared to 300 kDa chitosan (6.0 ± 0.1 %). Hence chitosan with more molecular weight showed better response towards preventing moisture gain.<br>• Chitosan (150 kDa) showed lower log values for mesophilic bacteria, yeasts and molds as compared to uncoated and 300 kDa chitosan as it has a less organized structure with lower crystallinity, resulting in a more homogeneous coating which is desirable since it provides a more effective | Dotto et al., 2015 |

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**Table 2** (*continued*)

| Coating Formulations Used | Papaya Form | Storage Conditions | Added Value | Effects and Potential Findings | References |
|---|---|---|---|---|---|
| | | | | barrier between the fruit and the external environment.<br>• Shelf life study of the samples show that the chitosan (150 kDa) is most suitable among the three formulations as it shows better anti-microbial activity and can extend the shelf life of papaya about 4 days (for mesophilic bacteria) and about 7days (for yeasts and molds). | |
| T1- Control coating: 1 % (w/v) chitosan;<br>T2- Coating treatment with 1 % (w/v) chitosan + 5 % (w/v) ethanolic extract of propolis (EEP) | Whole green coloured papaya fruits | Stored at a temperature of 25±3 °C with relative humidity between 65 and 70 % for 8 to 9 days | Propolis Extract | • The fruits covered with EEP + chitosan (T2) demonstrated a reduced deterioration index and infection diameter of the fungus *Colletotrichum gloeosporioides*, as compared to the control (T1) papayas.<br>• The control fruits showed a rapid decay during 4th day of storage hence increasing their deterioration index. Treated fruits were damage free till 4th day and then at the end of storage period the T2 showed only moderate damage.<br>• The treated fruits presented a higher content of anthocyanins (1.4 mg/100 g) in comparison with the control (0.9 mg/100 g) indicating a possible retardation of maturity.<br>• The treated fruits demonstrated a higher concentration of chlorophyll (3.2 - 4.5 mg/g) at the end of storage, compared to the control fruits (4.7 - 7.2 mg/g), confirming that the fruits covered with EEP + chitosan presented a slower pigmentation metabolism. | Barrera et al., 2015 |
| T1- Control (Uncoated);<br>T2- Chitosan- Oxidized Starch coating (1:3 w/w): chitosan solution (1% w/v) + oxidized starch slurry (3.5% w/v) | Ripe yellow coloured whole papaya fruit | Stored at room temperature (25 ± 1 °C) for 15 days | Oxidized starch | • Coating has a significant effect on the papaya fruit in terms of weight loss because results suggest that there was no significant weight change in coated papaya during the 15 day period but the uncoated papaya showed an increasing trend in weight loss percentage.<br>• Coated papaya (T2) showed a firmness reduction of 47.3 % whereas the uncoated papaya (T1) showed 92.02 % firmness loss.<br>• The ripening stage of uncoated papaya was attained at Day 5 but in the case of coated papaya the same stage was attained at Day 15, indicating delay in ripening.<br>• Log value for total coliforms, yeasts, mesophilic bacteria and fungi showed a distinguishable lead in case of uncoated papaya whereas slower growth of these microorganisms were observed in coated papaya. | Escamilla-García et al., 2018 |
| T1- Control;<br>T2- Chitosan 0.5 % (w/v);<br>T3- Chitosan 1.0 % (w/v);<br>T4- Chitosan 1.5 % (w/v);<br>T5- Chitosan 2.0 % (w/v);<br>T6- Chitosan 2.5 % (w/v);<br>T7- Chitosan 3.% (w/v); | Fresh whole papaya fruit | Stored under two conditions: cold storage (12±1°C) for 23 days, ambient temperature (28 ±1°C) for 9 days | - | • T1 experienced maximum weight loss (9.90 % at ambient storage and 8.97 % at cold storage) during 7 and 18 days of storage respectively, while T7 lost minimum weight (5.1 % at ambient and 4.5 % at cold storage) during 9 and 23 days of storage<br>• Papaya fruits treated with chitosan were recorded upto 48.15 % lesser change in colour than untreated fruits was evident from the colour (L, a and b) values at the end of storage.<br>• The moisture content of T1 decreased at faster rate and recorded 86.23 % (ambient storage) and 85.00 % (cold storage) during 7 and 18 days of storage, respectively while moisture content of T7 registered slower decrease and registered highest moisture content of 87.23% (ambient storage) and 88.25 % in cold storage during 9 and 23 days of storage, respectively.<br>• T1 fruits recorded lesser sensory scores while T7 fruits had higher score of overall acceptability of 7.92 (ambient storage) | Bhanushree et al., 2018 |

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**Table 2** (*continued*)

| Coating Formulations Used | Papaya Form | Storage Conditions | Added Value | Effects and Potential Findings | References |
|---|---|---|---|---|---|
| | | | | during 7 days of storage and 8.85 (cold storage) during 18 days of storage.<br>• T7 fruits showed an extended storage period up to 9 days (ambient storage) and 23 days (cold storage) as compared to T1 fruits (7 days at ambient and 18 days at cold storage) due to the delay in the ripening process. | |

from 0.5 to 3 %) on papaya fruits during storage at room temperature (28±1 °C) and cold storage (12±1 °C). The results indicated that during a storage period of 7 and 18 days at ambient temperature and cold storage, respectively, untreated papaya fruits experienced a maximum weight loss of 9.90 % and 8.97 %, while papaya fruits coated with 3 % chitosan exhibited a significantly lower weight loss of 5.1 % and 4.5 % respectively. These observations are in accordance with the results obtained by Bhanushree et al. (2018), which indicated that chitosan treated fruits (3% w/v) had the lowest weight loss and lowest moisture loss as compared to the untreated samples. The formation of a barrier against moisture and gases can result in reductions in weight loss and respiration rate, therefore delaying the onset of spoilage and extending the shelf-life of the product (Barrera et al., 2015; Chien et al., 2007). It was also observed that the softening of papaya fruits during storage was delayed by the application of chitosan, which resulted in lower firmness loss compared to untreated fruits. This observation may be attributed to the film-forming properties of chitosan, which can slow down the ripening process and thus minimise fruit softening. Similar results were obtained in other studies where papaya fruits were treated with chitosan in combination with ascorbic acid (Zhou et al., 2022), beeswax emulsion (Mukdisari et al., 2016), Tuna skin gelatin and black tea extract (Sekarina et al., 2023), pullulan coating (Zhang et al., 2019) and oxidised starch (Escamilla-García et al., 2018) respectively.

Papaya fruits treated with chitosan alone or along with some added value (ascorbic acid, oxidised starch, pullulan and propolis extract respectively) recorded lesser change in colour than untreated fruits, and this is evident from the colour (L, a* and b*) values at the end of storage period (Vilaplana et al., 2019; Zhou et al., 2022; Zhang et al., 2019; Bhanushree et al., 2018; Barrera et al., 2015). The colour loss occurs in untreated fruits due to the degradation of chlorophyll *by* ethylene gas and respiratory enzymes of papaya. The application of chitosan coating to papaya creates a reduced oxygen environment on the fruit surface, which leads to the inhibition of respiratory enzymes and ethylene synthetases, and this is achieved more effectively when chitosan is combined with multilayered coatings (Niu et al., 2019). These metabolic changes resulted in a delayed maturation process and increased stability of the fruit's cell wall, providing protection to chloroplasts and chlorophylls (Allanigue et al., 2017).

Various studies have shown that chitosan combined with other preservative components can more effectively manage post harvest losses in papaya as compared to sole chitosan treatment. Zhang et al. (2022) studied the combined effect of chitosan and ascorbic acid in maintaining the post-harvest quality of papaya by coating the papaya samples with different concentrations, including 1.5 % (w/v) ascorbic acid, 1.0 % (w/v) chitosan, and 1.5 % (w/v) ascorbic acid + 1.0 % (w/v) chitosan respectively. It was reported that chitosan combined ascorbic acid treatment significantly reduced $H_2O_2$ content (26.23–66.26 %) and MDA levels (28.06–43.36 %) at all storage dates as compared to control and also resulted in inhibition of softening enzyme activity and gene expression level of cell wall degrading enzymes such as CX, PG, PME, and β-GAL due to the presence of ascorbic acid, which activates or preserves the antioxidant enzyme activity, leading to scavenging of the reactive oxygen species which are responsible for oxidative damage (Soares et al., 2021). Similar results were obtained by Sekarina et al. (2023), where the researchers coated minimally processed papaya with edible coatings of chitosan - fish skin gelatine containing black tea extract in different concentrations (0, 5, 10 and 15 %, respectively) and reported that the antioxidant activity was found to be slightly higher in chitosan-tuna fish gelatin extract combined with 15 % black tea extract (59.26–72.62 %) as compared to control samples (66.97–72 %) and this may due to presence of tea polyphenols and chitosan, as both have strong antioxidant properties especially in terms of the ability to scavenge hydroxyl radicals and reactive oxygen species (Anggraini et al., 2016). It was also observed that microbial growth in the control papaya was faster as compared to the treatment sample with the addition of black tea extract, and this may be due to the antimicrobial effect of tea polyphenols and chitosan. Chitosan can interact with negatively charged residues on the surface of microbial cells by an electrostatic attraction so that it flocculates and absorbs on the surface of microorganisms, then inhibits the physiological metabolism of microorganisms (Badawy et al., 2017). On the other hand, tea polyphenols have the ability to cause coagulation of structural proteins, as well as binding to deoxyribonucleic acid molecules. Additionally, they can induce damage to the cell membranes and walls of microorganisms, ultimately leading to the inhibition of their growth (Bansal et al., 2013). Another study conducted by Barrera et al. (2015) investigated the effect of chitosan combined with propolis extract for post harvest treatment of papaya where papaya samples were treated with two different concentrations: 1 % chitosan (control) and 1 % chitosan combined with 5 % propolis extract. The results indicated that the deterioration index was lower in fruits treated with chitosan combined with propolis extract as compared to control, and this may be due to a synergistic antimicrobial effect between propolis and chitosan due to which the treatment fruits presented moderate damage, indicating a higher resistance to deterioration compared to the control papaya. Chitosan-coated films demonstrate a wide-ranging ability to inhibit bacterial growth, and when combined with propolis extract, the antibacterial effectiveness is further improved against all the pathogens tested, demonstrating the fungicidal and bactericidal effect of propolis along with chitosan (Torlak & Sert, 2013). Also, the fruits treated with chitosan combined with propolis extract exhibited a significant increase in chlorophyll concentration towards the end of their storage period, as compared to the control fruits. This outcome provides evidence that the fruits coated with chitosan combined with propolis experienced a delayed pigmentation process and a probable inhibition of ripening.

## 10. Conclusion and future scope

In conclusion, chitosan coating has been shown to be a promising approach to managing post-harvest losses in papaya. It has been found to have antimicrobial properties, preserve the quality of the fruit, and reduce water loss, all of which contribute to an extended shelf life and a decrease in overall losses. Therefore, the use of chitosan coating can contribute to the sustainability of papaya production and supply, as well as improve the economic viability of farmers. Future research could focus on optimising the use of chitosan coating by investigating the effect of different concentrations and application methods on papaya and combining it with other preservative components to boost its effect. Moreover, exploring the potential of combining chitosan coating with other preservation techniques, such as modified atmosphere packaging

or cold storage, could provide a more effective and integrated solution to post-harvest losses. Additionally, the potential health benefits of chitosan-coated papaya, such as increased antioxidant activity, could be further investigated. Overall, continued research on the use of chitosan coating in the management of post-harvest losses in papaya could have significant implications for the food industry and global food security.

## CRediT authorship contribution statement

**Harmanjot Singh:** Writing – original draft, Visualization, Validation, Resources, Methodology, Formal analysis, Data curation, Conceptualization. **Jasleen Kaur Bhasin:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Kshirod Kumar Dash:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Rafeeya Shams:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ayaz Mukarram shaikh:** Visualization, Validation, Software, Resources, Funding acquisition. **Kovács Béla:** Visualization, Validation, Resources, Project administration, Funding acquisition.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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### *Ethical Statement - Studies in humans and animals*

This study does not involve any animals or human subjects.

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