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Review article

Chitosan Maintains Postharvest Quality and Improves the Shelf Life of Fruits

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ABSTRACT

Fruits are excellent food items, and people love them. However, they perish quickly after harvest, leading to a 30-40% loss. Even the situation is worse in the developing and underdeveloped countries. Therefore, the fruits require special postharvest care and management to avoid massive loss. Chitosan (CTS), the deacetylated chitin derivative, can serve as a nice postharvest management kit for fruits because of its biocompatibility, biodegradability, film-forming capacity, and antimicrobial ability. This review aims to evaluate the performance of CTS in maintaining the physicochemical and microbial properties of fruits along with shelf life. CTS decreases fruit weight loss, slows down the process of color change, and increases fruit firmness. It delays the changes of fruits' chemical attributes, like total soluble solids and titratable acidity, along with rapid loss of vitamin C. CTS prevents the attack of pathogens like fungi, bacteria, algae, and molds and reduces the onset of diseases caused by the pathogens. CTS can also effectively extend the shelf life of fruits. Overall, chitosan can serve as an excellent eco-friendly postharvest fruit preservative catalyst.

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Introduction

Fruit is popular worldwide as it contains appreciable amounts of vitamins, minerals, and antioxidants (Palumbo et al., 2022). Moreover, they are rich in phenols, tannins, carotenoids, flavonoids, and secondary metabolites (Zheng and Wang, 2001). Fruit consumption has risen globally due to the growing interest in healthy and nutritious foods. However, the high perishability of fruits results in a limited shelf life, and the consumers do not have quality produce.

Fresh produce retains the inherent biological processes even after harvest. Due to shriveling, bulk loss, and low consumption, such a process may result in several undesirable changes that ultimately affect postharvest quality (Mahajan et al., 2014; Roobab et al., 2022). Fruits are, therefore, perishable living goods as well as metabolically active (Palumbo et al., 2022), and to preserve quality and minimize food loss and waste, different stakeholders like producers, storage managers, processors, and retailers must work together (Mahajan et al., 2014). As they undergo a series of ripening and senescence processes (Palumbo et al., 2022), the bulk of fruits never reach the consumers. Moreover, postharvest diseases affect fruit quality loss substantially, as they are more susceptible to fungi and pathogens during postharvest. Furthermore, wrong transportation and preservation also reduce fruit quality after harvesting (Riaz et al., 2021). Almost 40% of fruits and vegetables are wasted during handling and distribution at postharvest (Elik et al., 2019).

Postharvest quality attributes of fruit include different external characteristics like shape, size, color, firmness, texture, and internal parameters (chemical, physical, and microbial) (Lakshmi et al., 2017), including shelf life. Several strategies help to keep the fruit quality and to extend the shelf, such as chitosan (Aziz et al., 202; Parvin et al., 2023), edible oil treatments (Solgi and Ghorbanpour, 2014), packing materials (Azene et al., 2014), chemical treatments (Dovel, 2018), modified atmosphere (MA) (Irtwange, 2006), salicylic acid (Asghari and Aghdam, 2010; Win and Setha, 2022), cumin essential oil (Solgi and Ghorbanpour, 2014), clove extract (Nur Fatimma et al., 2018), calcium chloride (Madani et al., 2014; Dovel, 2018), *Aloe vera* (Shah and Hashmi, 2020; Jodhani and Nataraj, 2021), plant extracts (Kabir and Hossain, 2024) and so on. Chitosan (CTS) is prepared through the deacetylation of chitin, which can be a prospective alternative for retaining quality and extending the shelf life of fruit due to its film-forming ability, defense responses against microbes (bacteria, fungi, algae, and mold), biodegradability, and biocompatibility (Terry and Joyce, 2004; Fisk et al., 2008; Lin et al., 2011). Owing to its distinct physicochemical characteristics, it may be able to

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decrease transpiration and minimize the amount of oxygen uptake from the surrounding air. Thus, markedly extending the shelf life of fruit (Shi et al., 2013). Moreover, owing to its semipermeable film-forming capacity, CTS can change the internal environment by changing the permeability to water, oxygen, and carbon dioxide. It can reduce the rate of transpiration, respiration, mold growth, and fruit ripening, thus preserving the quality and prolonging the shelf life of fruit (Li and Yu, 2000). CTS coating may extend storage life and prevent fruit from physicochemical quality deterioration (Shi et al., 2013). This review evaluates the effectiveness of chitosan on the physicochemical and microbial attributes of fruits along with their shelf life.

Factors of postharvest losses of fruits

Fruits are notorious for having a limited shelf life and being highly metabolically active. The major causes of fruits' postharvest loss include mechanical, microbial, and environmental factors (Yahaya, 2005). These factors cause a significant loss between harvesting and consumption (Hayatu, 2000; Sani and Alao, 2006). Poor handling of fruits during harvesting, packing, shipping, and storing results in mechanical damage. Some insects and birds can also cause mechanical damage (Alao, 2000; Hayatu, 2000; Yahaya, 2005). In many circumstances, mechanical damage to fruits, such as bruising and cracking, makes them more vulnerable to pathogen attack and accelerates the rate of water loss and gas exchange. And such damaged fruits degrade more quickly during normal aging (Alao, 2000; Yahaya, 2005). Without the standard process of picking and harvesting, fruits may be damaged acutely. Fruits with fragile outer skin, such as apples, are particularly vulnerable to mechanical damage. As a result, weak fruits are more prone to pathological assaults such as rotting (Alao, 2000; Yahaya, 2005). Microbes like fungi, bacteria, yeast, and molds cause rotting. The most common pathogens in charge of fruits' rots are fungi like *Alternaria*, *Botrytis*, *Diplodia*, *Monilinia*, *Phomopsis*, *Rhizopus*, *Penicillium*, and *Fusarium*. Among bacteria, *Pseudomonas* and *Erwinia* cause severe damage. Bacteria attack fruits with a pH greater than 4.5, whereas fungi usually target more acidic tissue (Pasquariello et al., 2013).

Environmental factors like temperature and relative humidity (RH) influence the postharvest loss of fruits. High temperatures can increase the rate of respiration and may cause the breakdown of interior tissues. Though high temperature and high RH hasten fruit decay, a low temperature <5 °C decreases the pathogen attack (Díaz-Mula et al., 2012). Fruit decay depends on temperature and RH; the high RH causes less fruit decay if the existing temperature is about 0 °C. Moreover, if the RH is less than 90%, less microbe growth on the fruit surface is reported (Danladi, 2000).

Chitosan as a fruit preservative

CTS biopolymer can preserve fresh whole fruit, vegetables, and freshly cut slices of fruit and vegetables (Yu and Ren, 2013; Parijadi et al., 2022) alone or in combination with other compounds. Chitosan nanoparticles with different bio-preservatives cause desirable changes in fruit firmness, respiration, ethylene production, and total phenol content in the 'Cavendish' banana (Odetayo et al., 2022). A coating of 2% chitosan prevents the loss of fruit weight and vitamin C without deteriorating the desired sensory qualities in the Cavendish banana (Suseno et al., 2014). Shrimp chitosan coating extends banana shelf life to a maximum of 16 days at ambient conditions (Sikder and Islam, 2019). Moreover, bananas coated with CTS nanoparticles (2%) with either *A. vera* (50%) or *Moringa oleifera* (10%) decreases weight loss (by 23%), rate of respiration and ethylene generation. Starch and chitosan coating on banana at low drying temperature (50 °C) improves shelf life and quality up to 15 days in all coating situations (Alam et al., 2020). CTS coating prolongs the shelf life at low temperatures, and low temperature influences banana metabolism (Parijadi et al., 2022). Though 1% chitosan is most effective for banana, 4% chitosan shows the best results for dragon fruits regarding retaining quality and extending shelf life at storage (Hossain and Iqbal, 2016; Sikder and Islam, 2019; Prashanth et al., 2022).

Edible CTS coverings maintain the best quality strawberries at ambient temperature (20–25 °C), and the efficacy of CTS depends on the extraction procedures (Benhabiles et al., 2013). CTS and/or nanoparticles of CTS enhance the quality attributes of strawberries, including shelf life (Taha et al., 2020), and 1% CTS coating results in the best quality strawberry (Benhabiles et al., 2013). Shrimp CTS at 1.5% level provides the second-best result in the case of mango coating; however, at 1% concentration, it delays color change effectively (Monira et al., 2016; Aziz et al., 2021). The coating of a formulation having CTS (0.5%), *A. vera* gel (0.3%), and leaf extracts of papaya (0.2%) preserves the postharvest quality of mango at ambient storage conditions (Nga and Bac, 2021). Among the different concentrations of CTS and *A. vera* gel, 1.5% *A. vera* gel effectively maintains the quality and shelf life of large-sized mangoes at ambient conditions (Monira et al., 2016). Mango fruit coated with irradiated crab and shrimp CTS at low temperature (15±1°C) and high relative humidity (85%) show excellent potential for fruit quality and shelf life (Abbasi et al., 2009).

CTS modified with fatty acid N-acylation causes less peel discoloration and maintains the quality of papaya (Picard et al., 2013). CTS (0.75 g L^{-1}) also effectively retards the processes of ripening and softening and preserves high TSS in apricot (Jiang et al., 2010). Combined application of CTS and sodium silicate can effectively stop the postharvest diseases of jujube (Guo et al., 2019). CTS coating (0.3%) preserves superior visual and postharvest quality in carambola (Gol et al., 2015). Pineapple coated with CTS and incorporation of eugenol and *A. vera* gel has the effectiveness to preserve quality and extend shelf life for three weeks in storage (Basumatary et al., 2022).

Effects of chitosan on physical attributes of fruits

The physical properties of fruits are vital for the post-harvest management of fruits. Physical properties encompass fruit weight, firmness, peel color, and maturity. The adverse physiological change indicates fruit spoilage, e.g., higher respiration and transpiration cause weight loss, thus loss of flesh firmness and becoming more susceptible to microbial attack. In addition, such spoilage may result in considerable monetary loss to the farmer, importer, and retailers (Hossain and Iqbal, 2016). In fleshy fruit, physical damage caused during handling and transportation is the primary cause of the cell wall and starch degradation that results in firmness loss, which can lead to post-harvest losses and increased vulnerability to microbial attack (Manrique and Lajolo, 2004). CTS coating can keep the fruit firm by retarding loss through respiration and preventing moisture migration which delays textural changes caused by catabolism (Mani et al., 2018).

Table 1: Physical attributes of fruit as affected by chitosan

Attributes	**Fruits**	**Treatments**	**Effects**	**References**
Weight loss	Banana	Chitosan/ shrimp chitosan	Reduced	Suseno et al., 2014; Hossain and Iqbal, 2016; Sikder and Islam, 2019
	Mango	Chitosan	Reduced	Abbasi et al., 2009; Jongsri et al., 2016; Parvin et al., 2023
	Apple	Shrimp chitosan	Reduced	Abriana and Laga, 2016
	Feijoa/guavasteen	Shrimp chitosan	Reduced	Zárate-Moreno et al., 2023
	Cucumber	Chitosan	Reduced	El Ghaouth et al., 1991
	Bell pepper	Chitosan	Reduced	El Ghaouth et al., 1991
	Longan	Chitosan	Reduced	Jiang and Li, 2001
Fruit color	Banana	Chitosan	Delayed changes	Hossain and Iqbal, 2016
	Strawberry	Chitosan	Higher retention	Sánchez-González et al., 2010; Ghaani et al., 2020
	Apricots	Chitosan	Higher retention	Yildirim et al., 2019
	Blueberries	Chitosan	Delayed changes	Wang et al., 2018
	Kiwifruits	Chitosan	Higher retention	Zhang et al., 2016
	Pomegranate	Chitosan	Higher retention	Mirdehghan and Rahemi, 2011
	Longan	Chitosan	Reduced loss	Jiang and Li, 2001
	Mango	Chitosan with *Aloe vera* gel and papaya leaf extract	Reduced loss	Nga and Bac, 2021
Firmness	Mango	Chitosan	High	Jongsri et al., 2016
	Mango	Chitosan with 1-MCP	High	Wongmetha and Ke, 2012
	Mango	Chitosan with *Aloe vera* and papaya leaf extract	High	Nga and Bac, 2021
	Mango	Crab chitosan	High	Abbasi et al., 2009
	Banana	Chitosan	High	Aziz et al., 2021
	Dragon fruit	Chitosan	High	Prashanth et al., 2022

Edible coatings reduce the weight loss of fruit during transport and storage (Baldwin, 1994). Controlling fruit weight loss by the CTS coating is associated with several mechanisms. Some edible coatings make a barrier in gaseous exchange by providing permeability to O_2, CO_2, and ethylene, and thus, offer control on respiration and microbial growth (Cuq et al., 1995). Respiration and transpiration are the principal causes of weight loss in fruit (Zhu et al., 2008). The vapor pressure gradient between the fruit and air and gas exchanges significantly influences these processes (Bautista-Baños et al., 2006). On the surface of the fruit, CTS forms a thin, translucent layer that slows dehydration and reduces weight loss (Adiletta et al., 2019). Chitosan or shrimp chitosan reduces weight loss of banana (Suseno et al., 2014; Hossain and Iqbal, 2016; Sikder and Islam, 2019), mango (Abbasi et al., 2009; Jongsri et al., 2016; Parvin et al., 2023), apple (Abriana and Laga, 2016), feijoa (Zárate-Moreno et al., 2023), cucumber (El Ghaouth et al., 1991), bell pepper (El Ghaouth et al., 1991), and longan (Jiang and Li, 2001) (Table 1).

CTS also affects fruit color development. CTS delays color changes in banana and blueberries (Hossain and Iqbal, 2016; Wang et al., 2018), causes higher retention of color in strawberries, apricots, kiwifruits, and pomegranate (Sánchez-González et al., 2010; Mirdehghan and Rahemi, 2011; Zhang et al., 2016; Yildirim et al., 2019; Ghaani et al., 2020), and results in reduced loss of color in longan and mango (Jiang and Li, 2001; Nga and Bac, 2021) (Table 1).

CTS can reduce the loss of gaseous compounds like ethylene. They can also decrease the respiration rate, which results in delayed changes in peel color (Mani et al., 2018). CTS or crab CTS alone and with *A. vera* extract/papaya leaf extract/1-Methylcyclopropene (1-MCP) increases the firmness of mango, banana, and dragon fruit (Abbasi et al., 2009; Wongmetha and Ke, 2012; Jongsri et al., 2016; Aziz et al., 2021; Nga and Bac, 2021; Prashanth et al., 2022) (Table 1).

Effects of chitosan on chemical attributes of fruits

Chemical attributes of fruit mainly include titratable acidity (TA), total soluble solids (TSS), vitamin C, and pH. They play a significant role in fruit quality as some internal qualities of fruits, e.g., taste, aroma, and color, influence chemical parameters. Application of edible coatings like CTS may delay the loss in total anthocyanins, total phenolics, and antioxidant capacity of fruits (Ghasemnezhad et al., 2013) by reducing the breakdown rate of fructose, sucrose, and citric acid at storage (Gao et al., 2018). The sensory analysis reveals that carambola fruit with CTS (0.3%) and gum arabic (1%) coating delays changes in pH (Gol et al., 2015). Similarly, 0.25% CTS influences the pH changes in green apples (Sultana et al., 2020).

Table 2: Chitosan influences chemical attributes of fruit

Attributes	Fruits	Treatments	Effects	References
Titratable Acidity (TA)	Banana	Chitosan/ shrimp chitosan	Delayed changes	Hossain and Iqbal, 2016; Sikder and Islam, 2019
	Carambola	Chitosan and gum arabic	Delayed changes	Gol et al., 2015
	Dragon fruit	Chitosan	Reduced decrease	Prashanth et al., 2022
	Strawberry	Shrimp chitosan	Nonsignificant	Benhabiles et al., 2013
	Mango	Chitosan	Reduced decrease	Jongsri et al., 2016
	Ber	Chitosan	Delayed changes	Hesami et al., 2021
Total Soluble Solid (TSS)	Banana	Chitosan/ shrimp chitosan	Delayed changes	Hossain and Iqbal, 2016; Sikder and Islam, 2019
	Mango	Chitosan-pullulan composite	Delayed changes	Kumar et al., 2021
	Carambola	Chitosan and gum arabic	Delayed changes	Gol et al., 2015
	Dragon fruit	Chitosan	Reduced decrease	Prashanth et al., 202
	Ber	Chitosan	Delayed changes	Hesami et al., 2021
Vitamin C	Mango	Chitosan	Reduced loss	Parvin et al., 2023
	Banana	Chitosan	Reduced loss	Suseno et al., 2014
	Mango	Chitosan, *Aloe vera* and papaya leaf extract	Reduced loss	Nga and Bac, 2021
	Apple	Shrimp chitosan	Reduced loss	Abriana and Laga, 2016

CTS or shrimp CTS alone and with gum arabic delays changes in titratable acidity (TA) of banana, carambola, and ber (Gol et al., 2015; Hossain and Iqbal, 2016; Sikder and Islam, 2019; Hesami et al., 2021), reduces the decrease of TA in dragon fruit and mango (Jongsri et al., 2016; Prashanth et al., 2022), and has no effect in TA of strawberry (Benhabiles et al., 2013) (Table 2). CTS coatings delay the breakdown of organic acid content (Gao et al., 2018) and reduce moisture loss (Adiletta et al., 2019), resulting in less TA loss, which indicates slow ripening (Reddy et al., 2000). Therefore, CTS may act as a barrier to O_2 or decrease the supply of O_2 to the surface of the fruit, which slows the respiration rate and higher TA in coated fruits (Jiang and Li, 2001). CTS or shrimp CTS alone and with gum arabic and CTS-pullulan composite delays changes in total soluble solid (TSS) in banana, mango, carambola, and ber (Gol et al., 2015; Hossain and Iqbal, 2016; Sikder and Islam, 2019; Hesami et al., 2021; Kumar et al., 2021;) and reduces the decrease of TSS in dragon fruit (Prashanth et al., 2022) (Table 2). Numerous investigations have reported that the CTS coating slows the ripening of fruits by reprogramming the carbon metabolism process, which regulates the sugar level in the TSS value of fruit at storage (Ali et al., 2011; Silva et al., 2018).

CTS or shrimp CTS alone and in combination with *A. vera* extract/papaya leaf extract reduces vitamin C loss in banana, mango, and apple (Suseno et al., 2014; Abriana and Laga, 2016; Nga and Bac, 2021; Parvin et al., 2023) (Table 2). Fruits lose vitamin C during storage due to physiological changes (Kerch, 2015). CTS treatment inhibits the oxidation of vitamin C by lowering enzyme activity and delaying the decline of vitamin C content during storage, creating an oxygen permeability barrier (Bal, 2018).

Effects of chitosan on fruits microbial properties

CTS generally reduces the disease incidence and disease severity in fruits. CTS coating may act as a barrier against several microbial attacks on fruit during storage by preventing the ability to absorb oxygen (Parijadi et al., 2022). CTS coating is effective against some fungi, algae, and bacteria (Hossain and Iqbal, 2016). Moreover, it prevents fungi from spreading and minimizes spoilage regardless of the fruits' ripening ability (Lam and Diep, 2003). CTS may inhibit the growth of microorganisms on fruit by inducing the defense enzyme chitinase (Mauch et al., 1984) that hydrolyzes the chitin in the cell wall of fungi (El-Ghaouth et al., 1991; Hou et al., 1998). Therefore, the antifungal and antimicrobial properties protect fruits against fungi and microbes (Nga and Bac, 2021).

CTS or shrimp CTS or crab CTS reduces the disease incidences in banana, mango, and ber (Jitareerat et al., 2007; Abbasi et al., 2009; Hossain and Iqbal, 2016; Jongsri et al., 2016; Aziz et al., 2021; Hesami et al., 2021) (Table 3). CTS or shrimp CTS alone and in combination with 1-MCP reduces disease severity (DS) in bananas (Hossain and Iqbal, 2016; Sikder and Islam, 2019; Aziz et al., 2021), delays DS in mango (Wongmetha and Ke, 2012), and inhibits DS in longan (Jiang and Li, 2001) (Table 3). CTS exhibits a dual mechanism of action as it inhibits the growth of fungi that cause decay and foodborne infections while it produces host tissue resistance responses (Romanazzi et al., 2017).

Table 3. Disease incidence and severity of fruits as affected by chitosan

Attributes	Fruits	Treatments	Effects	References
Disease incidence	Banana	Chitosan / shrimp chitosan	Reduced	Hossain and Iqbal, 2016; Aziz et al., 2021
	Mango	Crab chitosan	Reduced	Abbasi et al., 2009
	Mango	Chitosan	Reduced	Jitareerat et al., 2007; Jongsri et al., 2016
	Ber	Chitosan	Reduced	Hesami et al., 2021
Disease severity	Banana	Chitosan / shrimp chitosan	Reduced	Hossain and Iqbal, 2016; Sikder and Islam, 2019; Aziz et al., 2021
	Mango	Chitosan with 1-MCP	Delayed	Wongmetha and Ke, 2012
	Longan	Chitosan	Inhibited	Jiang and Li, 2001

Shelf-life of fruits as affected by chitosan

A food product's shelf life is the limited time following production and packaging, during which it maintains the necessary quality under controlled storage conditions. This quality level makes it acceptable for human consumption (Nicoli et al., 2012). A fruit's shelf life is often defined as the length of time that a fruit maintains an appropriate level of sensory, physico-chemical, and nutritional quality while remaining safe regarding microbiological standards (Franks, 1993). Different shelf-life indicators of fruit are weight loss, firmness, TSS, pH, TA, and sensory attributes, e.g., appearance, brightness, color, odor, flavor, browning, texture, and sweetness. The microbial characteristics of shelf-life evaluation are disease incidence, disease severity, and % spoilage. CTS coating improves quality and extends the shelf life of fruits at postharvest. The edible coating of CTS can prolong the shelf life of fruits as it reduces respiration, thus impeding ripening and decay-induced senescence (Hossain and Iqbal, 2016; Sikder and Islam, 2019). They can also prevent loss of moisture and aroma by inhibiting oxygen penetration (Parijadi et al., 2022) and preventing shrinkage (Abriana and Laga, 2016).

CTS prolongs the shelf life of banana, ber, sapota, papaya, and dragon fruit (Anu et al., 2015; Dotto et al., 2015; Hossain and Iqbal, 2016; Dwivany et al., 2020; Aziz et al., 2021; Prashanth et al., 2022) (Table 4). Shrimp CTS also prolongs the shelf life of bananas, apples, strawberries, and feijoa (El Ghaouth et al., 2007; Sikder and Islam, 2019; Sultana et al., 2020; Zárate-Moreno et al., 2023). Similarly, irradiated CTS and CTS-pullulan (50:50) and pomegranate peel extract extend the shelf life of mango (Abbasi et al., 2009; Kumar et al., 2021) (Table 4).

Table 4: Shelf life of fruits affected by chitosan

Attributes	Fruits	Treatments	Effects	References
Shelf life	Mango	Irradiated chitosan	Extended	Abbasi et al., 2009
	Banana	Shrimp chitosan	Extended	Sikder and Islam, 2019
	Apple	Shrimp chitosan	Extended	Sultana et al., 2020
	Strawberry	Shrimp chitosan	Increased	El Ghaouth et al., 2007
	Feijoa/guavasteen	Shrimp chitosan	Extended	Zárate-Moreno et al., 2023
	Banana	Chitosan	Prolonged	Hossain and Iqbal, 2016; Dwivany et al., 2020; Aziz et al., 2021
	Banana	Chitosan biopolymer	Increased	Yu and Ren, 2013
	Mango	Chitosan-pullulan (50:50) and pomegranate peel extract	Prolonged	Kumar et al., 2021
	Ber	Chitosan	Prolonged	Hesami et al., 2021
	Sapota	Chitosan	Prolonged	Anu et al., 2015
	Dragon fruit	Chitosan	Prolonged	Prashanth et al., 2022
	Papaya	Chitosan	Prolonged	Dotto et al., 2015

Conclusion

Bio-preservatives are alternatives to hazardous chemical preservatives for postharvest fruit management, and they have good efficacy, low residues, and little or no toxicity to non-target organisms. CTS is an eco-friendly bio-preservative obtained from chitin-rich natural sources. CTS decreases fruit weight loss, slows down the process of color change, and increases fruit firmness. It delays the changes of total soluble solids and titratable acidity along with the fast loss of vitamin C. CTS prevents attack of pathogens like fungi, bacteria, algae, and molds and minimizes the onset of diseases. It also extends the shelf life of fruits effectively. Thus, CTS improves fruit physicochemical and microbial properties along with shelf life.

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Competing Interest

The authors report that there are no competing interests to declare.

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