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Chitosan and other edible coatings to extend shelf life, manage postharvest decay, and reduce loss and waste of fresh fruits and vegetables

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Fresh fruits and vegetables contain high percentage of water and continue metabolic activity after being harvested, resulting in ripening, increased sensitivity to decay-causing fungi, and consequent loss and waste. Edible coatings are prepared from naturally occurring renewable sources and can contribute to reducing waste, respecting environment, and consumer health. Chitosan and other edible coatings form a thin layer surrounding fresh produce that acts as a protective agent, extending shelf life, and have the potential to control their ripening process and maintain nutritional properties of the coated product. This review discusses recent research on the application of chitosan and other edible coatings to prevent fungal decay, keep the quality, and reduce fresh product waste.

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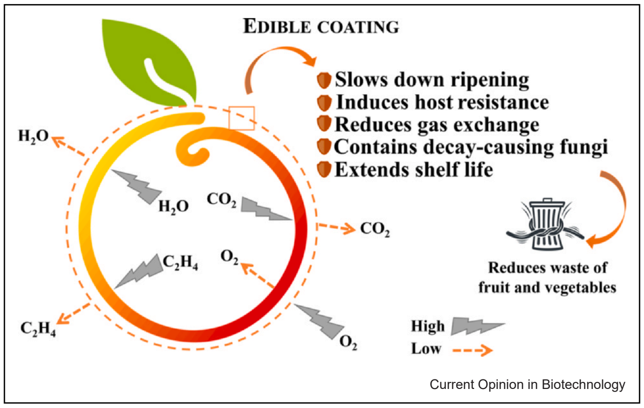
Introduction

The rapidly increasing world population makes it challenging to ensure global food security and to provide sufficient production of highly nutritious and high-quality food in sustainable ways. Fruits and vegetables contribute importantly to healthy human diets and help prevent malnutrition [1]. Fresh product is highly perishable, and once harvested, needs to be handled using appropriate technologies to maintain quality and prolong shelf life [2]. Over time, quality characteristics such as color, flavor, weight, nutritional value, and bioactive compounds deteriorate as a result of senescence. In addition, plant diseases cost the global economy around $220 billion annually and reduce crop productivity and quality, leading to rising food prices and global food insecurity [3]. Reducing fresh fruit and vegetable loss and waste can help decrease the pressure on food-production systems, particularly within the context of finite natural resources and climate change [4]. Furthermore, there is an increased consumer awareness of pesticide residues in foods, which has motivated the search for natural and environmentally friendly alternative strategies to control preharvest and postharvest diseases [5•,6]. The use of edible coatings with antifungal properties has emerged as a technology to protect fruits and vegetables from postharvest decay-causing fungi. A wide range of studies demonstrated antimicrobial activity of edible coatings against *Botrytis cinerea*, *Colletotrichum* spp., *Penicillium* spp., and *Alternaria* spp. [7–9••]. Coatings can change in 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 respiration process [10] (Figure 1). Different edible coatings have been reported to preserve nutritional value of fruits similar or even better than the conventional packaging.

The number of studies on application of edible coatings on fresh products has increased considerably in recent years, demonstrating interest of the scientific community in the subject (Figure 2). Edible coatings were prepared from naturally occurring renewable sources such as

Figure 1



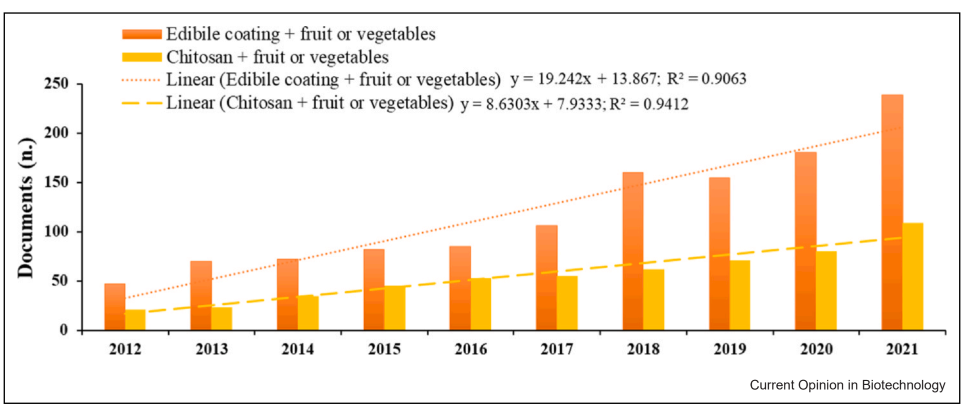
Main proprieties of edible coatings applied on fruits and vegetables, affecting the permeability to ethylene (C_2H_4), water (H_2O), oxygen (O_2), and carbon dioxide (CO_2).

polysaccharides, proteins, lipids, and extracts of various plants rich in bioactive compounds. Edible coatings are thin layers (usually less than 0.3 mm) that cover the surface of fresh fruits and vegetables and that can be eaten, while remaining undetectable on the tongue [11]. The studies involving chitosan represent around half of the total investigations on edible coating on fruits or vegetables (Figure 2). Other common edible coatings are pectin, *Aloe vera*, cassava starch, shellac, carnauba wax, and hydroxypropylmethyl-cellulose. Different methods could be used to apply edible coatings on fruits and vegetables, such as dipping, spraying, and brushing followed by air-drying [12–14].

Chitosan

A large number of edible coatings is 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 [15,16]. Chitosan 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. When applied on fruits and vegetables, chitosan can elicit host defenses, have antimicrobial activity toward decay-causing fungi, and produce a semipermeable film on a treated surface [17]. This edible coating has been widely applied in postharvest preservation of fresh fruits and vegetables. The scientific literature dealing with edible coatings using chitosan has increased in recent years. This can be explained by the importance of chitosan in plant protection as a natural fungicide and plant-defense booster, and its use to prolong the storage of an array of fruits and vegetables worldwide. In 2014, chitosan hydrochloride was approved as one of the first basic substances for plant protection by the European Union (Reg. EU 2014/563), and a second chitosan formulation was approved in 2022 (Reg. EU 2022/456) [5•]. This biopolymer can form a semipermeable film on fruit

Figure 2



Number of documents available on Scopus through searches with keywords “edible coating and fruit or vegetables; chitosan, postharvest or post-harvest and fruit or vegetables” in “Article title, Abstract, and Keywords” published over the last 10 years (
Source: Scopus, accessed on 26 June 2022; https://www.scopus.com).

Table 1

Examples of studies on the application of chitosan alone and combined with other compounds to control postharvest diseases of fresh fruits and vegetables.

Crop	Treatment	Decay			Host- defense elicitation	Reference
		Pathogen	Artificial inoculation/ natural infection[a]	Inhibition disease incidence/severity*		
Orange	Chitosan	*Penicillium digitatum*	AI	10.0%	–[b]	[22]
	Chitosan + pomegranate peel extract			49.0%	–	
	Chitosan + pomegranate peel extract/mL + *Wickerhamomyces anomalus*			95.0%	–	
Mango	Chitosan + thyme oil	*Colletotrichum gloeosporioides*	AI	77.6%*	–	[23]
		decay	NI	74.2%	–	
	Chitosan + *Lactobacillus fer-mentum*	*C. gloeosporioides*	AI	88.8%	–	[24]
		Botryodiplodia theobromae		77.7%		
Soursop	Chitosan	*C. gloeosporioides*	AI	85.0%	–	[25]
Apple	Chitosan	*Botrytis cinerea*	AI	13.6%	–	[7]
Tangerine		*P. digitatum*		27.7%		
	Chitosan + *Ficus hirta* Vahl. fruit extract	*P. italicum*	AI	56.4%	–	[26]
Strawberries	Chitosan	*B. cinerea*	NI	40.0%	–	[27]
	Chitosan + carotenoproteins			33.3%		
Papaya	Chitosan	*C. gloeosporioides*	NI	11.0%	PAL[c] (+++); FLS (++); UFGT (++)	[8]
	Chitosan + *Ruta graveolens* essential oil			36.8%		
Guava	Chitosan + *Cymbopogon citratus* essential oil	*Colletotrichum asianum*	AI	70.5%	–	[28]
		Colletotrichum fructicola		81.2%		
		Colletotrichum tropicale		47.2%		
		Colletotrichum siamense		33.0%		
Mango		*C. asianum*		63.0%		
		C. fructicola		91.8%		
		C. tropicale		78.2%		
		C. siamense		82.0%		
		Colletotrichum karstii		100%		
Papaya		*C. asianum*		91.2%		
		C. fructicola		74.6%		
		C. tropicale		28.0%		
		C. siamense		67.7%		
		C. karstii		84.4%		
Avocado	Chitosan	*C. gloeosporioides*	NI	72.0%	PAL (++); CHS (+); FLS (+); avfad 12–3 (++)	[29]

Table 1 (*continued*)

Crop	Treatment	Decay			Host- defense elicitation	Reference
		Pathogen	Artificial inoculation/ natural infection[a]	Inhibition disease incidence/severity*		
	Chitosan Chitosan + vanillic acid	*C. gloeosporioides*	NI	65.7% 92.8% Chitosan + caffeic acid	PAL (++); CHS (+); avfad 12–3 (+)	[30]
		88.5%				
	Chitosan	*Lasiodiplodia theobromae*, *C. gloeosporioides*	NI	40.0%	PAL (+++)	[31]
Chitosan + phenyl-alanine	*Alternaria* spp., *C. gloeosporioides*	NI	40.0%	PAL (+)	[32•]	
Grapes (cv. Kyoho) Grapes (cv. Shine Muscat)	Chitosan	*B. cinerea*	AI	63.4% 72.7%	–	[33]
Citrus maxima	Chitosan	*Lasiodiplodia pseudotheobromae*, *Alternaria alternata*, *P. digitatum*	AI	100%	–	[34]
Apricots	Chitosan + oregano essential oil	*A. alternata*	AI	42.8%	–	[35]
Cucumber	Chitosan	*Fusarium solani*	AI	57.1%*	–	[36]

* Severity inhibition.
[a] NI: naturally infected fruit; AI: artificially inoculated.
[b] –: No data available.
[c] PAL: phenylalanine ammonia lyase; FLS: flavonol synthase; UFGT: flavonoid 3-O-glucosyltransferase; CHS: chalcone synthase gene; avfad 12–3: fatty acid desaturase; + 3-fold; ++ = 3–10-fold; +++ > 10-fold.

Table 2

Examples of chitosan-based commercial products that are available for the control of diseases of fresh fruits and vegetables (modified by Romanazzi et al. [17]).

Product trade name	Company (country)	Formulation	Active ingredient (%)
Chito plant	ChiPro GmbH (Bremen, Germany)	Powder	99.9
Chitosano	Agrilaete (Palmanova, UD, Italia)	Powder	100
Chitosano denso		Liquid	50
OII-YS[a]	Venture Innovations (Lafayette, LA, USA)	Liquid	2
KaitoSol	Advanced Green Nanotechnologies Sdn Bhd (Cambridge, United Kingdom)	Liquid	12.5
Armour-Zen	Botry-Zen Limited (Dunedin, New Zealand)	Liquid	14.4
Biorend	Bioagro S.A. (Chile)	Liquid	1.25
Kiforce	Alba Milagro (Milano, Italy)	Liquid	6
FreshSeal	BASF Corporation (Mount Olive, NJ, USA)	Liquid	2.5
ChitoClear	Primex ehf (Siglufjordur, Iceland)	Powder	100
Bioshield	Seafresh (Bangkok, Thailand)	Powder	100
Biochikol 020 PC	Gumitex (Lowics, Poland)	Liquid	2
Kadozan	Lytone Enterprise, Inc. (Shanghai Branch, China)	Liquid	2
Kendal Cops	Valagro (Atessa, CH, Italy)	Liquid	4
Mastgrape	Enocea (Vegrar, VR, Italy)	Liquid	5
Prevatect	Ascenza (Saronno, VA, Italy)	Liquid	5
Chitosano Serbios	Serbios (Badia Polesine, RO, Italy)	Liquid	5
Chitosano	Bioplanet Srl (Cesena, Italy)	Liquid	1.9
Chitosano DC	Dal Cin Gildo Spa (Concorezzo, MB, Italy)	Liquid	2
Ibisco[b]	Gowan Italia s.r.l. (Faenza, RA, Italy)	Liquid	15

[a] Contains 6% yucca extract.
[b] The formulation is based on an average of 12.5% of COS (chito-oligosaccharides)-OGA (oligo-galacturonides), with a chitosan concentration of 15%.

and vegetable surfaces, which reduces respiration rate by adjusting the permeability of O_2 consumption and CO_2 production, and increased antioxidant activity [18]. Chitosan has broad-spectrum antimicrobial activity and proven inhibitory effects on a range of postharvest fungal pathogens [9••]. Landi et al. [8] showed that chitosan can act as an exogenous elicitor inducing activities of several defense-related enzymes in papaya fruit. In recent years, numerous studies have revealed the effectiveness of chitosan applied alone or combined with other natural compounds to maintain the physical properties of various fruits and vegetables (Table 1). The incorporation of various essential oils into polymer matrices has attracted widespread attention because this biopolymer reduced the volatility of essential oils and masks poor flavor of essential oils [19–21]. Several commercial chitosan formulations are available on the market to be used as a biopesticide (Table 2).

Other edible coatings

Edible coatings, such as shellac, carboxymethyl cellulose, hydroxypropyl methylcellulose, bee wax, and glycerol, can have different applications and activities (antifungal, antioxidant, and additives). Most of the studies on edible coatings focus on blending multiple polymers or incorporating different components to obtain edible materials with appropriate functionality that works with a specific fruit or vegetable requirement. Some edible coatings, such as hydroxypropyl methylcellulose, do not possess antimicrobial activities, but are used to enhance antifungal activity of incorporated essential oils [37]. The incorporation of essential oil with *Aloe vera* showed a higher rate of inhibition of *Colletotrichum musae* on banana than *Aloe vera* alone [38]. Application of edible coating to fruits and vegetables inhibited the infections by decay-causing fungi by 20–100% (Table 3). The combination of shellac with carvacrol or thymol reduced grapefruit decay and suppressed chilling injury [39]. The combination of carboxymethyl cellulose and stearic acid with phenylalanine reduced decay incidence and severity and improved the flavor of avocado fruit [32]. Pectin is a natural antifungal coating able to control postharvest decay of citrus [40••,41]. The coating of peach with pectin-containing rhubarb extract improved postharvest quality and prolonged shelf life [42]. Exopolysaccharide with *Lactiplantibacillus plantarum* was able to totally inhibit the growth of *Fusarium* spp., *Rhizopus stolonifer* on

Table 3

Example of edible coatings applied to fresh fruits and vegetables to manage postharvest decay and extend shelf life.

Crop	Treatment	Decay			Reference
		Pathogen	Artificial inoculation/ natural infection[a]	Inhibition of disease incidence/ severity*	
Grapefruit	Shellac + carvacrol Shellac + thymol	*Lasiodiplodia theobromae*	NI	26.0% 39.1%	[39]
Avocado	Carboxymethyl cellulose + stearic acid + phenylalanine	*Colletotrichum gloeosporioides* and *Alternaria* spp.	NI	80.0%	[32]
Mango	HPMC[b] + ginger essential oil	*C. gloeosporioides*	NI	38.0%*	[37]
	HPMC + plai or fingerroot essential oil		NI	20.0%*	
	HPMC + ginger essential oil		AI	42.5%*	
	HPMC + plai essential oil		AI	40.8%*	
	HPMC + fingerroot essential oil		AI	26.0%*	
	HPMC + bee wax	*C. gloeosporioides*	NI	66.6%	[47•]
Mandarin	HPMC + bee wax + potassium sorbate	*Lasiodiplodia theobromae*	AI	50.0%*	[48]
	HPMC + bee wax + sodium benzoate			38.0%*	
	HPMC + bee wax + sodium ethylparaben			25.0%*	
Orange	HPMC + bee wax + potassium sorbate or sodium benzoate			60.0%*	
	HPMC +bee wax +sodium ethylparaben			30.0%*	
	Pectin + bee wax + eugenol	*Penicillium digitatum*	AI	46.0%*	[40••]
Cherry tomato	Exopolysaccharide + *Lactiplantibacillus plantarum*	*Fusarium* spp., *Rhizopus stolonifer*	AI	100%	[43]
Banana	Aloe gel + lemon peel extract	*Colletotrichum musae*	NI	80%	[49]
	Aloe vera gel	*C. musae*	AI	25.1%	[38]
	Aloe vera gel + garlic essential oil			92.5%	
Tarocco orange cv Lempso	Pectin + calcium chloride + *Wickerhamomyces anomalus*	*P. digitatum* and *P. italicum*	NI	91.7%	[41]
Pomegranate 'Mollar de Elche'	HPMC + glycerol monostearate + sodium benzoate	*Botrytis cinerea* and *Penicillium* spp.	NI	78.5%	[50]
	HPMC + carnauba wax + sodium benzoate			64.2%	
Apple	Cassava starch + gellan gum	*B. cinerea*	AI	25.0%	[44]
Persimmon		*A. alternata*		44.0%	
Pear 'Early crisp'	Modified sweet potato starch + cumin essential oil	*A. alternata*	AI	70.0%*	[45]
Peach	Rhubarb + sodium alginate	*Penicillium expansum*	AI	35%	[42]
'Fino' lemon	Pregelatinized potato starch + sodium benzoate	*Geotrichum citri-aurantii*	AI	42.0%	[46]

* Severity inhibition.
[a] NI: naturally infected fruit; AI: artificially inoculated.
[b] HPMC: hydroxypropylmethyl cellulose.

the cherry tomato [43]. Starch-based coatings control pathogenic fungi and bacteria only if amended with antifungal ingredients, such as essential oil and sodium benzoate [44–46]. Therefore, the combination of different edible coatings with compounds presenting antifungal properties has emerged as alternative technology to protect fresh product from postharvest pathogenic fungi.

Conclusions

Many countries are increasingly restricting the use of synthetic pesticides, and export markets are demanding fruits and vegetables with residue levels of zero, or lower than the allowed thresholds established by official regulations. Researchers are continuously exploring the role of coatings made from natural ingredients that represent an environmentally friendly solution since they are biodegradable, can be consumed with the packaged product, and the main ingredients are produced from renewable resources. The use of chitosan and other edible coating has shown promising results in extending shelf life, maintaining quality through reduced gas exchange, slowing down ripening, and inducing host-defense mechanisms. Edible coating might complement or replace traditional preservation methods, but unfortunately, most of the studies are conducted at laboratory scale and only a limited number of coatings are available commercially. Further investigations are needed in semicommercial and commercial conditions to validate the effectiveness of trials run in small scale, and studies on sensory quality are mandatory to meet the market and consumer acceptance of the coated fresh fruits and vegetables.

Conflict of interest statement

The authors declare no conflict of interest.

Data availability

No data were used for the research described in the article.

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References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. FAO: **Fruit and vegetables – your dietary essentials. The International Year of Fruits and Vegetables, 2021, background paper**. Rom 2020, ⟨https://doi.org/10.4060/cb2395en⟩.

2. Jafarzadeh S, Nafchi AM, Salehabadi A, Oladzad-Abbasabadi N, Jafari SM: **Application of bio-nanocomposite films and edible coatings for extending the shelf life of fresh fruits and vegetables**. *Adv Colloid Interface Sci* 2021, **291**:102405, https://doi.org/10.1016/j.cis.2021.102405

3. Savary S, Willocquet L, Pethybridge SJ, Esker P, McRoberts N, Nelson A: **The global burden of pathogens and pests on major food crops**. *Nat Ecol Evol* 2019, **3**:430-439, https://doi.org/10.1038/s41559-018-0793-y

4. Nicastro R, Carillo P: **Food loss and waste prevention strategies from farm to fork**. *Sustainability* 2021, **13**:5443, https://doi.org/10.3390/su13105443

5. • Romanazzi G, Orçonneau Y, Moumni M, Davillerd Y, Marchand PA: **Basic substances, a sustainable tool to complement and eventually replace synthetic pesticides in the management of pre and postharvest diseases: reviewed instructions for users**. *Molecules* 2022, **27**:3484, https://doi.org/10.3390/molecules27113484.

   The review highlighted the rules and examples of application of basic substances, including chitosan, to control pre and postharvest diseases. The authors also highlighted increasing requirement from the EU retailers to provide fruits and vegetables with pesticide residue below the maximum limits.

6. Das S, Ghosh A, Mukherjee A: **Nanoencapsulation-based edible coating of essential oils as a novel green strategy against fungal spoilage, mycotoxin contamination, and quality deterioration of stored fruits: an overview**. *Front Microbiol* 2021, **12**:768414, https://doi.org/10.3389/fmicb.2021.768414

7. Wardana AA, Koga A, Tanaka F, Tanaka F: **Antifungal features and properties of chitosan/sandalwood oil Pickering emulsion coating stabilized by appropriate cellulose nanofiber dosage for fresh fruit application**. *Sci Rep* 2021, **11**:1-15, https://doi.org/10.1038/s41598-021-98074-w

8. Landi L, Peralta-Ruiz Y, Chaves-López C, Romanazzi G: **Chitosan coating enriched with *Ruta graveolens* L. essential oil reduces postharvest anthracnose of papaya (*Carica papaya* L.) and modulates defense-related gene expression**. *Front Plant Sci* 2021, **12**:765806, https://doi.org/10.3389/fpls.2021.765806

9. •• Rajestary R, Landi L, Romanazzi G: **Chitosan and postharvest decay of fresh fruit: meta-analysis of disease control and antimicrobial and eliciting activities**. *Compr Rev Food Sci* 2021, **20**:563-582, https://doi.org/10.1111/1541-4337.12672.

   A meta-analysis of the use chitosan to control postharvest decay of fresh fruits and vegetables taking in consideration antimicrobial activity, eliciting properties and decay control effects.

10. Karagöz Ş, Demirdöven A: **Effect of chitosan coatings with and without *Stevia rebaudiana* and modified atmosphere packaging on quality of cold stored fresh-cut apples**. *LWT* 2019, **108**:332-337, https://doi.org/10.1016/j.lwt.2019.03.040

11. Ribeiro AM, Estevinho BN, Rocha F: **Preparation and incorporation of functional ingredients in edible films and coatings**. *Food Bioprocess Technol* 2021, **14**:209-231, https://doi.org/10.1007/s11947-020-02528-4

12. Felicia WXL, Rovina K, Nur'Aqilah MN, Vonnie JM, Erna KH, Misson M, Halid NFA: **Recent advancements of polysaccharides to enhance quality and delay ripening of fresh produce: a review**. *Polymers* 2022, **14**:1341, https://doi.org/10.3390/polym14071341

13. Ganduri VR: **Evaluation of pullulan-based edible active coating methods on rastali and chakkarakeli bananas and their shelf-life extension parameters studies**. *J Food Process Preserv* 2020, **44**:e14378, https://doi.org/10.1111/jfpp.14378

14. Tahir HE, Xiaobo Z, Mahunu GK, Arslan M, Abdalhai M, Zhihua L: **Recent developments in gum edible coating applications for fruits and vegetables preservation: a review**. *Carbohydr Polym* 2019, **224**:115141, https://doi.org/10.1016/j.carbpol.2019.115141

15. Neto JR, Copes F, Chevallier P, Vieira RS, da Silva JVL, Mantovani D, Beppu MM: **Polysaccharide-based layer-by-layer nanoarchitectonics with sulfated chitosan for tuning anti-thrombogenic properties**. *Colloids Surf B* 2022, **213**:112359, https://doi.org/10.1016/j.colsurfb.2022.112359

16. Gao N, Du W, Zhang M, Ling G, Zhang P: **Chitosan-modified biochar: Preparation, modifications, mechanisms and applications**. *Int J Biol Macromol* 2022, **209**:31-49, https://doi.org/10.1016/j.ijbiomac.2022.04.006

17. Romanazzi G, Feliziani E, Sivakumar D: **Chitosan, a biopolymer with triple action on postharvest decay of fruit and vegetables: eliciting, antimicrobial and film-forming properties**. *Front Microbiol* 2018, **9**:2745, https://doi.org/10.3389/fmicb.2018.02745

18. Shah S, Hashmi MS: **Chitosan–Aloe vera gel coating delays postharvest decay of mango fruit**. *HEB* 2020, **61**:279-289, https://doi.org/10.1007/s13580-019-00224-7

19. Sánchez Aldana D, Aguilar CN, Contreras-Esquivel JC, Souza MP, Carneiro-da-Cunha MDG, Nevárez-Moorillón GV: **Use of a Mexican lime (*Citrus aurantifolia* Swingle) edible coating to preserve minimally processed mango (*Mangifera indica* L)**. *HEB* 2021, **62**:765-775, https://doi.org/10.1007/s13580-021-00347-w

20. Danila A, Muresan EI, Ibanescu SA, Popescu A, Danu M, Zaharia C, Türko˘glue GC, Erkan G, Staras AI: **Preparation, characterization, and application of polysaccharide-based emulsions incorporated with lavender essential oil for skin-friendly cellulosic support**. *Int J Biol Macromol* 2021, **191**:405-413, https://doi.org/10.1016/j.ijbiomac.2021.09.090

21. Zhang WL, Jiang HT, Rhim JW, Cao JK, Jiang WB: **Effective strategies of sustained release and retention enhancement of essential oils in active food packaging films/coatings**. *Food*

Chem 2022, **367**:130671, https://doi.org/10.1016/j.foodchem.2021.130671

22. Kharchoufi S, Parafati L, Licciardello F, Muratore G, Hamdi M, Cirvilleri G, Restuccia C: **Edible coatings incorporating pomegranate peel extract and biocontrol yeast to reduce *Penicillium digitatum* postharvest decay of oranges**. *Food Microbiol* 2018, **74**:107-112, https://doi.org/10.1016/j.fm.2018.03.011

23. Shah S, Hashmi MS, Qazi IM, Durrani Y, Sarkhosh A, Hussain I, Brecht JK: **Pre-storage chitosan-thyme oil coating control anthracnose in mango fruit**. *Sci Hortic* 2021, **284**:110139, https://doi.org/10.1016/j.scienta.2021.110139

24. Ranjith FH, Adhikari B, Muhialdin BJ, Yusof NL, Mohammed NK, Ariffin SH, Hussin ASM: **Peptide-based edible coatings to control postharvest fungal spoilage of mango (*Mangifera indica* L.) fruit**. *Food Control* 2022, **135**:108789, https://doi.org/10.1016/j.foodcont.2021.108789

25. Ramos-Guerrero A, González-Estrada RR, Romanazzi G, Landi L, Gutiérrez-Martínez P: **Effects of chitosan in the control of postharvest anthracnose of soursop (*Annona muricata*) fruit**. *Rev Mex Ing Quim* 2020, **19**:99-108, https://doi.org/10.24275/rmiq/Bio527

26. Chen C, Nie Z, Wan C, Chen J: **Preservation of Xinyu tangerines with an edible coating using *Ficus hirta* Vahl. fruits extract-incorporated chitosan**. *Biomolecules* 2019, **9**:46, https://doi.org/10.3390/biom9020046

27. Hajji S, Younes I, Affes S, Boufi S, Nasri M: **Optimization of the formulation of chitosan edible coatings supplemented with carotenoproteins and their use for extending strawberries postharvest life**. *Food Hydrocoll* 2018, **83**:375-392, https://doi.org/10.1016/j.foodhyd.2018.05.013

28. Oliveira PDL, de Oliveira KÁR, dos Santos Vieira W, Câmara MPS, de Souz EL: **Control of anthracnose caused by *Colletotrichum* species in guava, mango and papaya using synergistic combinations of chitosan and *Cymbopogon citratus* (DC ex Nees) Stapf. essential oil**. *Int J Food Microbiol* 2018, **266**:87-94, https://doi.org/10.1016/j.ijfoodmicro.2017.11.018

29. Mokgalapa N, Akinola A, Shoko T, Pillai SK, Sivakumar D: **Chitosan molecular weights affect anthracnose incidence and elicitation of defence-related enzymes in avocado (*Persea americana*) cultivar 'Fuerte'**. *Int J Food Microbiol* 2022, **366**:109561, https://doi.org/10.1016/j.ijfoodmicro.2022.109561

30. Osondu HAA, Akinol SA, Shoko T, Pillai SK, Sivakumar D: **Coating properties, resistance response, molecular mechanisms and anthracnose decay reduction in green skin avocado fruit ('Fuerte') coated with chitosan hydrochloride loaded with functional compounds**. *Postharvest Biol Technol* 2022, **186**:111812, https://doi.org/10.1016/j.postharvbio.2021.111812

31. Obianom C, Romanazzi G, Sivakumar D: **Effects of chitosan treatment on avocado postharvest diseases and expression of phenylalanine ammonia-lyase, chitinase and lipoxygenase genes**. *Postharvest Biol Technol* 2019, **147**:214-221, https://doi.org/10.1016/j.postharvbio.2018.10.004

32. • Saidi L, Duanis-Assaf D, Galsarker O, Maurer D, Alkan N, Poverenov E: **Elicitation of fruit defense response by active edible coatings embedded with phenylalanine to improve quality and storability of avocado fruit**. *Postharvest Biol Technol* 2021, **174**:1-10, https://doi.org/10.1016/j.postharvbio.2020.111442.

The authors demonstrated that coating the avocado fruit with combination of chitosan and phenylalanine improved the control of postharvest decay compared to the use of chitosan alone. Chitosan with phenylalanine act as elicitor, increasing expression of several genes related to defense in avocado fruit.

33. Zhang Z, Zhao P, Zhang P, Su L, Jia H, Wei X, Fang J, Jia H: **Integrative transcriptomics and metabolomics data exploring the effect of chitosan on postharvest grape resistance to *Botrytis cinerea***. *Postharvest Biol Technol* 2020, **167**:111248, https://doi.org/10.1016/j.postharvbio.2020.111248

34. Cuong HN, Minh NC, Hoa NV, Giang DH, Hieu NV, Nam PV: **Antifungal activity of squid pen chitosan nanoparticles against three fungal pathogens in various citrus fruits *in vitro* and *in vivo***. *Coatings* 2022, **12**:235, https://doi.org/10.3390/coatings12020235

35. Guo S, Li T, Chen M, Wu C, Ge X, Fan G, Yang T: **Sustainable and effective Chitosan-based edible films incorporated with OEO nanoemulsion against apricots' black spot**. *Food Control* 2022, **138**:108965, https://doi.org/10.1016/j.foodcont.2022.108965

36. Istúriz-Zapata MA, Hernández-López M, Correa-Pacheco ZN, Barrera-Necha LL: **Quality of cold-stored cucumber as affected by nanostructured coatings of chitosan with cinnamon essential oil and cinnamaldehyde**. *LWT* 2020, **123**:109089, https://doi.org/10.1016/j.lwt.2020.109089

37. Klangmuang P, Sothornvit R: **Active coating from hydroxypropyl methylcellulose-based nanocomposite incorporated with Thai essential oils on mango (cv. Namdokmai Sithong)**. *Food Biosci* 2018, **23**:9-15, https://doi.org/10.1016/j.fbio.2018.02.012

38. Khaliq G, Abbas HT, Ali I, Waseem M: **Aloe vera gel enriched with garlic essential oil effectively controls anthracnose disease and maintains postharvest quality of banana fruit during storage**. *Hortic Environ Biotechnol* 2019, **60**:659-669, https://doi.org/10.1007/s13580-019-00159-z

39. Yan J, Zhang J, Hu C, Deng L, Ritenour MA: **Use of carvacrol and thymol in shellac coating to control stem-end rot on 'Ruby Red' grapefruit and maintain fruit quality during simulated storage and marketing**. *Sci Hortic* 2020, **272**:109606, https://doi.org/10.1016/j.scienta.2020.109606

40. •• Alvarez MV, Palou L, Taberner V, Fernández-Catalán A, Argente-Sanchis M, Pitta E, Pérez-Gago MB: **Natural pectin-based edible composite coatings with antifungal properties to control green mold and reduce losses of 'Valencia' oranges**. *Foods* 2022, **11**:1083, https://doi.org/10.3390/foods11081083.

The first research work in which pectin-based edible coatings formulated with natural essential oils or plant extracts were applied to citrus fruit for the control *Penicillium digitatum.*

41. Strano MC, Restuccia C, De Leo R, Mangiameli S, Bedin E, Allegra M, Quartieri A, Cirvilleri G, Pulvirenti A: **Efficacy of an antifungal edible coating for the quality maintenance of Tarocco orange fruit during cold storage**. *J Crop Prot* 2021, **148**:105719, https://doi.org/10.1016/j.cropro.2021.105719

42. Li XY, Du XL, Liu Y, Tong LJ, Wang Q, Li JL: **Rhubarb extract incorporated into an alginate-based edible coating for peach preservation**. *Sci Hortic* 2019, **257**:108685, https://doi.org/10.1016/j.scienta.2019.108685

43. Álvarez A, Manjarres JJ, Ramírez C, Bolívar G: **Use of an exopolysaccharide-based edible coating and lactic acid bacteria with antifungal activity to preserve the postharvest quality of cherry tomato**. *LWT* 2021, **151**:112225, https://doi.org/10.1016/j.lwt.2021.112225

44. Sapper M, Palou L, Pérez-Gago MB, Chiralt A: **Antifungal starch–gellan edible coatings with thyme essential oil for the postharvest preservation of apple and persimmon**. *Coatings* 2019, **9**:333, https://doi.org/10.3390/coatings9050333

45. Oyom W, Xu H, Liu Z, Long H, Li Y, Zhang Z, Bi Y, Tahergorabi R, Prusky D: **Effects of modified sweet potato starch edible coating incorporated with cumin essential oil on storage quality of 'early crisp'**. *LWT* 2022, **153**:112475, https://doi.org/10.1016/j.lwt.2021.112475

46. Soto-Muñoz L, Martínez-Blay V, Pérez-Gago MB, Fernández-Catalán A, Argente-Sanchis M, Palou L: **Starch-based antifungal edible coatings to control sour rot caused by *Geotrichum citri-aurantii* and maintain postharvest quality of 'Fino' lemon**. *J Sci Food Agric* 2022, **102**:794-800, https://doi.org/10.1002/jsfa.11414

47. • Sousa FF, Junior JSP, Oliveira KT, Rodrigues EC, Andrade JP, Mattiuz BH: **Conservation of 'Palmer' mango with an edible coating of hydroxypropyl methylcellulose and beeswax**. *Food Chem* 2021, **346**:128925, https://doi.org/10.1016/j.foodchem.2020.128925.

Edible coating based on hydroxypropyl methylcellulose and beeswax reduced the incidence of anthracnose on mango. A treatment with beeswax can be tested in commercial application.

48. Guimarães JE, de la Fuente B, Pérez-Gago MB, Andradas C, Carbó R, Mattiuz BH, Palou L: **Antifungal activity of GRAS salts against**

***Lasiodiplodia theobromae in vitro* and as ingredients of hydroxypropyl methylcellulose-lipid composite edible coatings to control Diplodia stem-end rot and maintain postharvest quality of citrus fruit**. *Int J Food Microbiol* 2019, **301**:9-18, https://doi.org/10.1016/j.ijfoodmicro.2019.04.008

49. Jodhani KA, Nataraj M: **Synergistic effect of Aloe gel (*Aloe vera* L.) and Lemon (*Citrus limon* L.) peel extract edible coating on shelf life and quality of banana (*Musa* spp.)**. *J Food Meas Charact* 2021, **15**:2318-2328, https://doi.org/10.1007/s11694-021-00822-z

50. Di Millo B, Martínez-Blay V, Pérez-Gago MB, Argente-Sanchis M, Grimal A, Baraldi E, Palou L: **Antifungal hydroxypropyl methylcellulose (HPMC)-lipid composite edible coatings and modified atmosphere packaging (MAP) to reduce postharvest decay and improve storability of 'Mollar De Elche'pomegranates**. *Coatings* 2021, **11**:308, https://doi.org/10.3390/coatings11030308