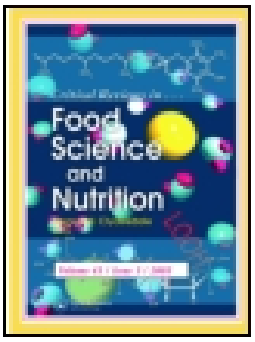

Critical Reviews in Food Science and Nutrition

ISSN: 1040-8398 (Print) 1549-7852 (Online) Journal homepage: https://www.tandfonline.com/loi/bfsn20

Biodegradable films based on fruit puree: a brief review

Julia Rabelo Vaz Matheus, Roberta Fontanive Miyahira & Ana Elizabeth Cavalcante Fai

CRITICAL REVIEWS IN FOOD SCIENCE AND NUTRITION
https://doi.org/10.1080/10408398.2020.1772715

REVIEW

Biodegradable films based on fruit puree: a brief review

Julia Rabelo Vaz Matheus[a], Roberta Fontanive Miyahira[b], and Ana Elizabeth Cavalcante Fai[a,b]

[a]Food and Nutrition Graduate Program, Federal University of the State of Rio de Janeiro (UNIRIO), Rio de Janeiro, RJ, Brazil; [b]Basic and Experimental Nutrition, Institute of Nutrition, Rio de Janeiro State University (UERJ), Rio de Janeiro, RJ, Brazil

ABSTRACT

The production of fruit-film packaging has attracted increasing attention in scientific research due to the packaging's environmentally friendly, nontoxic, and edible characteristics. The development of alternative packaging contributes to both minimizing the environmental impacts caused by the large consumption of non-biodegradable plastics and favoring the reduction of postharvest loss/waste of fruit. In addition, these fruit films have the potential to be functional packages due the presence of antioxidant and antimicrobial compounds that can migrate to the food matrix, acting as natural additives. The use of fruit puree to develop biodegradable films can be simpler and more practical than the developed of films from fruit flour or extracts, reducing the time, energy, and resources necessary to prepare the film-forming solution. A better understanding of the mechanical properties, bioactive compounds, and potential applications is interesting in terms of prospecting new specific ways to produce and use these films. In this study, we briefly review the general aspects of fruit puree films, highlighting their characterization for use as food packaging.

KEYWORDS

Biodegradable film; edible film; fruits; puree; bioplastic

Introduction

Agroindustrial products can be used as raw material in innovative processes contributing to the reduction of postharvest loss/waste and to the solution of pollution problems related to their disposal (Banerjee et al. 2017; Fai et al. 2016). The development of biodegradable films based on fruit is an alternative that has been explored (Brito et al. 2019; Fai et al. 2016; Tulamandi et al. 2016; Martelli et al. 2013; Azeredo et al. 2012). These natural films not only aim to help reduce the use of environmentally unfriendly polymers (Otoni et al. 2017; Brito et al. 2011) but are also aligned with the precepts of the circular economy since it promotes greater use of inputs, generating value-added products and reducing waste (Brito-Nogueira et al. 2020; Jurgilevich et al. 2016). Fruits-based films are technically feasible and have interesting functional characteristics as they can be flexible and edible, and they add a higher value to the commercially unwanted or undesired fruits (Brito et al. 2019; Fai et al. 2016).

There are several natural polymers that generate biodegradable films, such as polysaccharides (pectin, starch, chitosan, and cellulose) and proteins (collagen, casein, and soy protein) (Cazón et al. 2017). Several studies have used fruit, vegetables and their byproducts as a basis for the formation of films with good characteristics (Monteiro et al. 2017; Fai et al. 2016; Azeredo et al. 2012). More than 35 fruit and vegetable species have already been reported as film forming (Otoni et al. 2017).

The production of films from fruit puree presents good results in terms of mechanical properties and gas barrier (Rojas-Graü et al. 2006). The films made with puree often preserve the sensorial characteristics of the fruit, an additional attraction compared to other odorless and colorless films (Martelli, Barros, and Assis 2014). The filmogenic base of fruit purees is mainly composed of pectin and cellulose, and the diversity of sugars functions as a plasticizer (Otoni et al. 2017).

One of the ways to obtain a filmogenic base is by processing fruit into puree; from there several techniques can be used to form the film (Otoni et al. 2017). There are advantages and disadvantages to developing films using puree. A better understanding of the mechanical properties, bioactive compounds, and potential applications of these films is interesting in terms of prospecting new specific ways to produce and use them. In this study, we briefly review the general aspects of fruit puree films, highlighting their characterization for use as food packaging.

Biodegradable fruit films: why use puree-based formulations?

The production of packaging film that is based on biological materials is growing and has attracted increasing attention in scientific fields because these materials are eco-friendly (biodegradable) and usually edible (Ferreira et al. 2016). Specifically, fruits have been suggested to replace petroleum-based packaging, mainly for food packaging, because large-

CONTACT Ana Elizabeth Cavalcante Fai bethfai@yahoo.com.br Food and Nutrition Graduate Program, Federal University of the State of Rio de Janeiro (UNIRIO), Rio de Janeiro/RJ, Brazil.

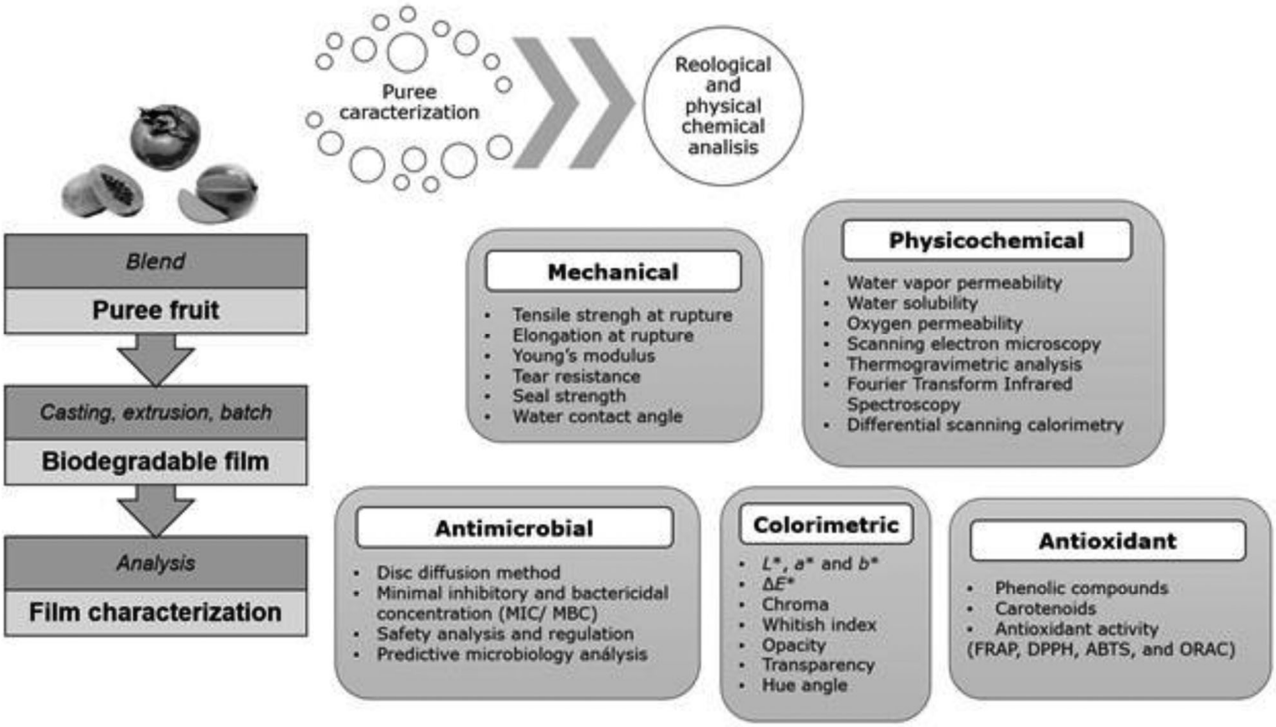

Figure 1. Main steps in the process of fruit puree film elaboration and examples of possible characterization analysis.

scale production and difficulty in handling generate a lot of waste (Ferreira et al. 2015). In addition, the development of these products maximizes the fruits utilization and is in accordance to the circular economy (Brito-Nogueira et al. 2020; Jurgilevich et al. 2016).

The main advantages of using fruit as a raw material for film-forming solutions are its potential in producing functional films with adequate mechanical and barrier properties (Cazón et al. 2017; Rojas-Graü et al. 2006). Although these films cannot completely replace the utilization of conventional synthetic polymers, they can potentially be employed as an alternative to quick-use packing with immediate disposal (Barros-Alexandrino, Tosi, and Assis 2017; Song and Zheng 2014); they efficiently preserve food stability and reduce the interaction of the food with the surrounding environment (Peltzer et al. 2017; Otoni et al. 2017). Moreover, these films may have features inherent in fruits that can be considered an additional attraction when compared to conventional. Some of these special attributes are color, flavor, and bioactive and nutritional compounds, which are usually preserved in biodegradable films (Barros-Alexandrino, Tosi, and Assis 2017; Otoni et al. 2014). These compounds can migrate to the food matrix, acting as natural additives (Salgado et al. 2015). Using the fruit puree to develop biodegradable films is usually more simple and practical (Barros-Alexandrino, Tosi, and Assis 2019; Jirukkakul 2016; Martelli, Barros, and Assis 2014; Du et al. 2012; Matheus et al. 2020), compared to developing films from flour (Jirukkakul 2016) or extracts (Maniglia et al. 2019; Pelissari et al. 2017), because it requires less time and energy and fewer resources in the preparation of the film-forming solution, requiring no processing steps of raw material.

A high number of fruits have been described as biodegradable film-forming matrices. It is important to note that to most of these developed bioplastics, plasticizers are added, such as glycerol and pectin (Martelli, Barros, and Assis 2014; Otoni et al. 2014; Espitia et al. 2014; Martelli et al. 2013; Ravishankar et al. 2012; Matheus et al. 2020); nanoparticles, such as chitosan nanoparticles (Barros-Alexandrino, Tosi, and Assis 2019; Lorevice et al. 2012); nanoemulsion (Otoni et al. 2014); and nanoreinforcements, such as nanofibers, and cellulose whiskers/composite (Suppakul et al. 2016; Lorevice et al. 2012; Azeredo et al. 2012). These additives are meant to improve the mechanical and barrier properties of films through their interaction with the polymer network (Barros-Alexandrino, Tosi, and Assis 2017).

Characterization of puree films

Film characterization is directly related to the most suitable application for food packaging. The main groups of analysis for such films are mechanical, physicochemical, colorimetric, antioxidant and antimicrobial, as summarized in Figure 1.

Mechanical and physicochemical properties

The main analyses within mechanical properties are tensile strength at rupture (TS), elongation at rupture (ER), and Young's modulus (YM). These indicators are used to describe mechanical resistance and elongation. The TS and ER represent the maximum tension and stretching to which the film can be submitted before rupture, respectively (Capitani et al. 2016). The YM represents how stiff the film is (Espitia et al. 2014). Other analyses are also used to characterize and understand the structure of the films, such as tear resistance and seal strength. The tear resistance of the films evaluates the work required for tearing the material (tear propagation resistance), which is important in evaluating the potentiality of the film to serve as packaging and sealing. The seal strength is, as the name implies, the required strength of a unit-width film to seal before it breaks (Tulamandi et al. 2016).

The mechanical properties are directly affected by the addition of plasticizers in the film formulation, since these molecules tend to decrease the interactions among adjacent polymer chains which results in a decrease of TS and increase of ER. In other words: plasticizers usually help increase the flexibility and elongation of the films, but if the amount is large, it can lead to excessive interaction and stiffening of the film (Gonçalves et al. 2019; Delgado et al. 2018; Reis et al. 2015). Several studies have observed that the addition of chitosan nanoparticles (Azeredo et al. 2012) and cellulose reinforcement (Barros-Alexandrino, Tosi, and Assis 2019; Martelli et al. 2013; Lorevice et al. 2012) are effective in increasing the values of TS and of YM. The addition of nanoreinforcement aims to balance the plasticizing action of the fruit puree, which is mainly due to high amounts of sugars in the pulp that decrease intermolecular forces (Martelli et al. 2013). Otoni et al. (2014) have observed that the addition of papaya puree reduced the rigidity and increased ER in pectin films.

The physical properties are affected by the mobility of polymeric chains, which is related to the type and concentration of plasticizers, film purity, the hydrophilicity and hydrophobicity ratio of film components, water activities, and thickness of films (Gonçalves et al. 2019; Delgado et al. 2018). Usually, these properties are evaluated using parameters such as water solubility (WS), water vapor permeabilities (WVP), oxygen permeabilities and water contact angle.

Water vapor permeability indicates how easily water vapor can penetrate a biodegradable film. It includes sorption, diffusion and desorption processes in which water vapor dissolves on one side of the film and diffuses on the other side, reaching the atmosphere (Delgado et al. 2018; McHugh and Krochta 1994). Water vapor permeability depends on WS and its mobility and diffusion through the film matrix. Thus, chemical structure, polarity, molecular weight, degree of polymerization and crystallinity, and the presence of plasticizers are factors that affect permeability. Water solubility is mostly affected by the amount of hydrophilic molecules present during film formulation. Thus, the addition of a plasticizer such as glycerol increases WS rate (Delgado et al. 2018). McHugh and Senesi (2000) observed that the addition of lipids during the film formulation of apple puree reduced WVP. Rojas-Graü et al. (2006) also observed that the addition of the essential oils to apple puree film decreased WVP. Otoni et al. (2014) have presented that cinnamaldehyde nanoemulsions and papaya puree reduce the WVP in pectin films.

Other analyses are usually performed to better understand the structure of the film matrix. Thermal analyses are used to predict which molecular bonds are present in the film matrix. Thermogravimetric analysis involves monitoring the film mass loss as a function of temperature or time by submitting it to a controlled heating program. The mass loss occurs due to the volatilization of the degradation products. This result indicates the thermal stability of the films, which might be related to its polymeric structure and their molecular interactions (Moliner et al. 2016). Fourier-transform infrared spectroscopy measurements are also performed on films to identify a possible chemical interaction between the polymeric network molecules (Gonçalves et al. 2019). Scanning electron microscopy allows the visualization of the morphological characteristics of the film surface and favors a greater understanding of the structural organization of polymers in the film matrix (Delgado et al. 2018; Espitia et al. 2014).

Table 1 shows mechanical and physicochemical properties of fruit puree films as well as the countries and journals involved in the publication of these results.

Optical properties

The visual aspect of food packaging is an important factor for good consumer acceptance. Thus, some colorimetric parameters are used, mainly L^*, a^* and b^* coordinates, color difference (ΔE^*), chroma value (C^*), opacity percentage, and transparency. The coordinates L^* represent lightness and range from 0 (black) to 100 (white); a^* and b^* measure color, of which negative values are greenness (- a^*) and blueness (- b^*) and positive values are redness (+ a^*) and yellowness (+ b^*) (Fai et al. 2016; Espitia et al. 2014). The difference in color (ΔE^*) is usually, used to measure the difference between two colors; the higher values indicate the highest color intensity (Nouraddini, Esmaiili, and Mohtarami 2018). The C^* represents color saturation, ranging from dull (low value) to vivid (high value) (Fai et al. 2016). The high opacity in fruit-based films is common because of the presence of agglomeration: The phenolic compounds, protein, lipids, and fiber in the film matrix form a dark surface. This can be favorable in preventing food oxidation through UV light (Nouraddini, Esmaiili, and Mohtarami 2018). In general, the addition of plasticizers promotes the opening of the molecular structure of polymer chains, facilitating light penetration into the film, reducing its opacity (Fakhouri et al. 2015). In addition, the drying process of films influences their internal structure, affecting how light will pass through the film (Gonçalves et al. 2019). The transparency value of the film is indirectly related to opacity, where the highest value corresponds to a lower film transparency (higher opacity) (Capitani et al. 2016). Sufficiently bright and transparent fruit puree films can present a vibrant color which is a differential feature of food packaging compared to films without pureed fruit.

Antimicrobial properties

Several authors have found antimicrobial action in fruit puree films incorporated with potential antimicrobial additives, as shown in Table 2. Edible films containing natural

Table 1. Main characterization of fruit puree films and countries/journals involved in the publication of these results.

Fruit puree film composition	TS (MPa)	ER (%)	YM (MPa)	WVP (gmm/kPahm^2)	WS (%)	Countries involved in the study	Journal	References
Acerola puree (100g) with sodium alginate (1.6g), distilled water (50 mL), corn sirup (4g)	3.16 ± 0.61	28.26 ± 2.88	15.35 ± 1.68	0.41 ± 0.17	–	Brazil	LWT - Food Science and Technology	Azeredo et al. 2012
Apple puree (26% w/w solution) with ascorbic and citric acid (0.5% w/w), pectin (3% w/w) and glycerol (3% w/w)	–	–	–	13.58 ± 0.20	–	USA	Journal of Food Science	McHugh and Senesi 2000
Apple puree (260g) with pectin solution (705 g of 3% w/w pectin solution added from ascorbic and citric acids - 0.25% w/w - and glycerol - 3% w/w) (batch cast method)	1.45 ± 0.13	45.94 ± 2.54	–	4.39 ± 0.20	–	USA	J. Agric. Food Chem	Du et al. 2008b
Apple puree (260 g) with pectin solution (705 g of 3% w/w pectin solution added from ascorbic and citric acids – 0.25% w/w – and glycerol – 3% w/w)	3.47 ± 0.28	48.60 ± 3.40	5.16 ± 0.60	3.62 ± 0.64	–	USA	Journal of Food Science	Du et al. 2009a
Apple puree solution (26% w/w - 260 g) with alginate solution (2% w/w - 715 g) added 10 g of N-acetylcysteine (1% w/w) and 15 g of glycerol (1.5% w/w)	2.90 ± 0.52	51.06 ± 3.89	7.07 ± 1.09	4.95 ± 0.43	–	Spain; USA	Journal of Food Engineering	Rojas-Graü et al. 2006
Apple puree with solution of high methoxyl pectin of 3% (30 g of pectin into 970 g of water) and vegetable glycerin (12%)	3.44 ± 0.27	47.01 ± 3.77	5.10 ± 0.43	3.91 ± 0.28	–	USA	Journal of Food Science	
Apple puree solution (26% w/w - 260 g) with pectin solution (3% w/w – 700 g) added 5 g of ascorbic and citric acids (0.5% w/w) and 30 g of glycerol (3% w/w)	0.64 ± 0.02	25.4 ± 2.10	5.06 ± 0.54	7.04 ± 0.63	–	Spain; USA	Journal of Agricultural and Food Chemistry	Rojas-Graü et al. 2006
Banana puree concentration of 4.5% (g dry weight per 100 g total solution), whose banana puree was prepared with 750g banana puree with 250 g distilled water and 0.2% w/w solution of citric and ascorbic acid. Added glycerol (5 g.100g^{-1} of dry weight puree)	3.20 ± 0.50	23.00 ± 3.00	21.00 ± 3.00	3.03 ± 0.15	–	Brazil	Journal of Food Science	Martelli et al. 2013
Banana puree concentration of 6% (g dry weight per 100 g total solution), whose banana puree was prepared with 750g banana puree with 250 g distilled water and 0.2% w/w solution of citric and ascorbic acid.	6.90 ± 0.06	13.00 ± 1.00	120.00 ± 17.00	–	–	Brazil	Polímeros	Martelli, Barros, and Assis 2014
Banana puree solution (5% w/w) with glycerol (2% w/w) treated with potassium metabisulfite (100 mg.kg^{-1} of banana)	1.45 ± 0.05	17.73 ± 0.50	–	0.24 ± 0.01	40.73 ± 1.86	Thailand	International Food Research Journal	Jirukkakul 2016
Banana puree solution (5% w/w) with glycerol (2% w/w) treated with ascorbic acid (470 mg.kg^{-1} of banana)	2.02 ± 0.25	17.73 ± 1.97	–	0.24 ± 0.01	37.68 ± 2.35			
Guava puree (10.0 g) with hydroxypropyl methylcellulose (4.0 g.100 mL^{-1} of distilled water)	5.40 ± 0.20	2.20 ± 0.20	–	2.09 ± 0.10	96.00 ± 1.10	Brazil	Journal of Nanoscience and Nanotechnology	Lorevice et al. 2012
Guava puree (475 mL) with sorbitol (0.57 g on a dry basis) and pectin (2.85 g on a dry basis)	8.55	26.29	141.57	6.24	–	Brazil	Carbohydrate Polymers	Viana et al. 2018
Mango puree (475 mL) with sorbitol (0.57 g on a dry basis) and pectin (2.85 g on a dry basis)	9.45	25.55	124.16	8.31	–			
Indian gooseberry puree (30% w/w) with methylcellulose (4% w/v) and polyethylene glycol (0.67% w/v)	33.53	2.21	891.91	–	–	Thailand; Republic of Korea	Food Control	Suppakul et al. 2016
Mango puree (100g/100g film-forming solution)	4.09 ± 0.12	44.07 ± 0.98	19.85 ± 0.51	2.66 ± 0.06	–	Brazil; USA	Journal of Food Science	Azeredo et al. 2009
Manga puree (100g/100g film-forming solution)	1.20	18.50	8.30	213.20		Thailand	Postharvest Biology and Technology	Sothornvit and Rodsamran 2008
Papaya puree (8 g w/w) with distilled water (100 ml) and starch (2 g w/w)	5.21 ± 0.10	22.25 ± 0.17	–	8.45 ± 0.67	77.54 ± 0.04	India; USA	Food Packaging and Shelf Life	Tulamandi et al. 2016
Papaya puree concentration of 15% (g dry weight per 100 g total solution), whose papaya puree was prepared with 750 g papaya with 250 g distilled water and 0.2% w / w citric and ascorbic acid	–	–	–	3.50 ± 0.50	–	Brazil	Polymer Engineering and Science	Barros-Alexandrino, Tosi, and Assis 2019
Papaya puree (3% w/w solution) with low methylester pectin (1.5% w/w solution)	246.10 ± 22.96	30.00 ± 3.86	–	3.10 ± 0.10	–	Brazil	Food Hydrocolloids	Otoni et al. 2014
Papaya puree (3% w/w solution) with hight methylester pectin (1.5% w/w solution)	191.60 ± 39.38	37.37 ± 5.41	–	3.26 ± 0.02	–			
Peach puree (26% puree w/w in aqueous solutions)	–	–	–	4.18 ± 0.18	–	USA	Journal of Food Science	
Apricot puree (26% puree w/w in aqueous solutions)	–	–	–	4.29 ± 0.07	–			
Apple puree (26% puree w/w in aqueous solutions)	–	–	–	5.84 ± 0.07	–			
Pear puree (26% puree w/w in aqueous solutions)	–	–	–	7.78 ± 0.12	–			
Persimmon puree (100g/100g film-forming solution)	1.30 ± 0.18	17.71 ± 2.50	10.94 ± 2.20	6.50 ± 0.24	68.80 ± 6.02	Brazil	–	Matheus et al. 2020
Tomato puree (300 g) with pectin solution (700 g of 3% w/w pectin solution) (continuous-cast method)	13.70 ± 1.80	9.60 ± 1.40	316.90 ± 40.80	2.20 ± 0.15	–	USA	Journal of Food Science	Du et al. 2008a
Tomato puree (300 g) with pectin solution (700 g of 3% w/w pectin solution)	9.13 ± 1.38	32.20 ± 4.00	64.20 ± 14.10	2.77 ± 0.54	–	USA	Journal of Food Science	Du et al. 2009b

Table 2. Studies reporting fruit puree film incorporated with potential antimicrobial additives.

Fruit puree film incorporated with potential antimicrobial additives	Main conclusions	Reference
Açaí puree (26% w/w) with pectin solution of 3% w/w (70.5% w/w), citric and ascorbic acids (0.25% w/ w) and glycerol (3% w/w) added the apple skin polyphenols and thyme essential oil (both ranging from 0.13 to 6.07%)	• Films incorporated with antimicrobial compounds showed action against *Listeria monocytogenes*, being the thyme essential oil with stronger effect than apple skin polyphenols.	Espitia et al. 2014
Apple puree (260g) with pectin solution (705 g of 3% w/w pectin solution) added from ascorbic and citric acids – 0.25% w/w - glycerol – 3% w/w, and carvacrol (0, 0.5, 1.0, and 1.5 % w/w)	• The inhibition area was dependent upon the concentration of carvacrol in films. • Film disks containing 1.0 or 1.5% carvacrol formed *Escherichia coli* O157:H7 growth inhibition halo (similar inhibition zones at 24 and 48 h incubation). • High-performance liquid chromatography analysis of the films indicated that the carvacrol concentrations (~1.0 %) and their bactericidal effect did not change significantly during storage of the tomato films up to 49 days at 5 and 25 °C.	Du et al. 2008b
Apple puree (260 g) with pectin solution (705 g of 3% w/w pectin solution), ascorbic and citric acids – (0.25% w/w), glycerol (3% w/w) and cinnamon, allspice, and clove bud essential oils (0, 0.5, 1.0, 1.5, and 3% w/w)	• The apple films incorporated by essential oils were antibacterial in a concentration-dependent manner, manly to against *L. monocytogenes* than against the *Salmonella enterica*. • The overlap test of the inhibitory zones produced by the 3 pathogenic bacteria were higher after 24 h than after 48 h. • Clove bud oils were active against 3 foodborne pathogens by contact direct (with bacteria) and indirect (by vapors emanating from film).	Du et al. 2009a
Apple puree solution (26% w/w – 260 g) with pectin solution (3% w/w – 700 g) added 5 g of ascorbic and citric acids (0.5% w/w), 30 g of glycerol (3% w/w) and oregano, lemongrass, and cinnamon essential oils (0, 0.05, 0.075, 0.1 and 0.5% w/w)	• The apple puree films incorporated by oregano oil inhibited the growth of the *E. coli* O157: H7 in a concentration-dependent manner. Oregano oil was 5 times more effective against *E. coli* O157:H7 than cinnamon and lemongrass oil at the same concentration. The same results was found to apple puree film formulation incorporated with essential oils.	Rojas-Graü et al. 2006
Apple puree solution (26% w/w – 260 g) with alginate solution (2% w/w – 715 g) added 10 g of N-acetylcysteine (1% w/w), 15 g of glycerol (1.5% w/w) and oils (0.1% w/w to oregano and carvacrol oil; 0.5% w/w to lemongrass, citral, cinnamon oil and cinnamaldehyde)	• All compounds inhibited the growth of *E. coli* O157:H7, mainly carvacrol and oregano oil. • The antimicrobial activity against *E. coli* O157:H7 was higher in films with oregano oil/carvacrol compared than lemongrass oil/citral and cinnamon oil/ cinnamaldehyde at 0.5% w/w. • Carvacrol was 5 times more effective against *E. coli* O157:H7 than cinnamaldehyde and citral at the same concentration.	Rojas-Graü et al. 2006
Banana puree concentration of 4.5% (g dry weight per 100 g total solution), whose banana puree was prepared with 750 g banana puree with 250 g distilled water and 0.2% w/w solution of citric and ascorbic acid. Added glycerol (5 g.100g^{-1} of dry weight puree) and chitosan nanoparticles (0.2% w/w)	• The chitosan nanoparticles in films did not present any perceptible inhibition on the bacterial growth (*E. coli* and *Staphylococcus aureus*) when compared to the film without chitosan nanoparticles.	Martelli et al. 2013
Papaya puree (3% w/w solution) with low or hight methylester pectin (1.5% w/w solution) and cinnamaldehyde (1.0% wt.)	• The papaya puree films incorporated by cinnamaldehyde nanoemulsions of different droplet sizes inhibited the growth of the *E. coli*, *S. enterica*, *L. monocytogenes* and *S. aureus*. • Nanoemulsions of smaller droplets presented greater antimicrobial properties • Greater zones of inhibition were formed for gram-positive bacteria (*L. monocytogenes* and *S. aureus*) than for gram-negative bacteria (*E. coli* and *S. enterica*).	Otoni et al. 2014
Persimmon puree (100g/100g film-forming solution)	• *S. aureus* and *Salmonella* sp. were extremely sensitive and very sensitive to films based on persimmon, respectively. Other bacteria were not sensitive to the film tested.	Matheus et al. 2020
Tomato puree (300 g) with pectin solution (700 g of 3% w/w pectin solution) with carvacrol (0, 0.5, 0.75, 1.0, and 1.5% w/w)	• Increased carvacrol concentration in the films induced a greater extent of inhibition of bacterial growth. • Film disks containing 0.75% or 1.0% carvacrol formed *E. coli* O157:H7 growth inhibition halo (similar inhibition zones at 24 and 48 hours incubation). Films incopored with 0% and 0.5% carvacrol did not inhibit growth of the bacteria. • High-performance liquid chromatography analysis of the films indicated that the carvacrol concentrations and their bactericidal effect did not change significantly during storage of the tomato films up to 3 months at 5 to 25 °C.	Du et al. 2008a
Tomato puree (300 g) with pectin solution (700 g of 3% w/w pectin solution) and oregano, allspice, and garlic essential oils (0, 0.5, 1.0, 1.5, and 3% w/w)	• The tomato films incorporated by essential oils inhibited the growth of the 3 pathogens in a concentration-dependent manner, manly to against *L. monocytogenes* than against the *S. enterica*. • Oregano oil in the films was what else inhibited the growth of all 3 pathogenic bacteria. • Films incorporated with garlic oil were not effective against *E. coli* O157:H7 or *S. enterica*, just to *L. monocytogenes* at all concentrations levels after 24 h of incubation. • After 48 h, the antibacterial action against *L. monocytogenes* of the essential oils disappeared, except by highest concentration remained active. In general, the overlap test of the inhibitory zones produced by the 3 pathogenic bacteria were higher after 24 h than after 48 h.	Du et al. 2009b

antimicrobial additives are interesting as a potential treatment to extend food products' shelf life and to reduce the risk of pathogen growth, for example, *Escherichia coli*, *Salmonella* sp., *Staphylococcus aureus*, and *Listeria monocytogenes* (Zhu et al. 2014; Ravishankar et al. 2012; Du et al. 2008a).

The capacity of antimicrobial compounds to migrate from edible active packaging to coated foods is related to their interaction with water and other solvents/solutes in the films' matrices (Martucci et al. 2015; Du et al. 2008a) whose action of antimicrobials can occur through direct contact with the food surface or by being slowly released to them (Otoni et al. 2017).

The addition of an antimicrobial compound does not assure this property of the film, since physical contact between the bacteria and the added antimicrobial compound is required. This compound must in turn be well dispersed in the film matrix, with its free active groups available on the film surface for proper bacterial interaction (Martelli et al. 2013). For example, Martelli et al. (2013) added chitosan nanoparticles to banana puree films and reported good activity against gram-positive and gram-negative bacteria; however, no antimicrobial activity was detected in these films chitosan nanoparticles incorporated.

The tendency to use antimicrobially active packaging for food is also associated with the search for fresher and more natural foods that are microbiologically safe, with a shelf life adequate to the consumer's routine and with the lowest content of food chemical additives possible.

Perspectives for the application of fruit puree films as food packaging

The use of fruit-based films as biodegradable food packaging is still a major challenge, and efforts must be made to improve a barrier to water vapors and gases and to have adequate mechanical, optical, and WS properties (Rojas-Graü et al. 2006). In the process, the chemical composition and the inter- and intramolecular interactions of the polymer matrix, using additives or not, should be studied. Some strategies to circumvent these difficulties involve incorporating both molecules with reinforced properties, in order to increase mechanical resistance, and lipophilic surfactants, which can improve water vapor barrier properties in hydrophilic films (Comaposada et al. 2018; Parreidt et al. 2018; Otoni et al. 2017).

One conclusion that can be drawn from this review is that it is essential to research different formulations to produce fruit puree films and to extensively characterize them to define the most suitable application for them. For example, more sensitive foods, liquid foods, or products exuding aqueous solution require packaging with an effective water barrier, while ready-to-eat foods that will melt or dissolve in boiling water or even directly in the mouth should be packed with highly soluble films (Otoni et al. 2017; Ferreira et al. 2016; Pitak and Rakshit 2011).

Packaging is one of the fields most intensively studied in terms of life cycle assessment, and it plays an especially important role in the food industry. Environmental impacts related to packaging must account for the material and energy resources used for its production as well as the disposal issues after its use. To reduce these impacts, lighter and more flexible polymers have been sought instead of rigid, more renewable and efficient processing materials (Wikström et al. 2014).

In addition to biodegradability aspects and the biocompatibility of fruit puree film with food material, it is important to note that when an edible, fruit-based film is applied to a food product, part of it is absorbed. Thus, it may be assumed that a fruit-based film incorporates bioactive compounds into the product, providing an additional nutritional and bioactive benefit (e.g., antioxidants and functional carbohydrates) beyond the expected technological attributes. Additionally, the inclusion of natural antimicrobial additives might improve microbiological quality and supply considerable advantages in terms of the safety and shelf life of products, reducing the amount of chemical additives needed. Further investigation of improvement steps in the development, characterization, and application of fruit film puree as food packaging is recommended over the next years.

Acknowledgements

The authors are grateful to UNIRIO, UERJ, Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro (FAPERJ) for their financial support.

Disclosure statement

The authors declare no conflict of interest.

ORCID

Roberta Fontanive Miyahira http://orcid.org/0000-0002-4202-2756
Ana Elizabeth Cavalcante Fai http://orcid.org/0000-0002-8594-2667

References

Azeredo, H. M. C., L. H. C. Mattoso, D. Wood, T. G. Williams, R. J. Avena-Bustillos, and T. H. Mchugh. 2009. Nanocomposite Edible Films from Mango Puree Reinforced with Cellulose Nanofibers. *Journal of Food Science* 74:N31–N35. doi: 10.1111/j.1750-3841.2009.01186.

Azeredo, H. M. C., K. W. E. Miranda, M. F. Rosa, D. Nascimento, and M. R. Moura. 2012. Edible films from alginate-acerola puree reinforced with cellulose whiskers. *LWT - Food Science and Technology* 46 (1):294–7. doi: 10.1016/j.lwt.2011.09.016.

Banerjee, J., R. Singh, R. Vijayaraghavan, D. MacFarlane, A. F. Patti, and A. Arora. 2017. Bioactives from fruit processing wastes: Green approaches to valuable chemicals. *Food Chemistry* 225:10–22. doi: 10.1016/j.foodchem.2016.12.093.

Barros-Alexandrino, T. T., M. M. Tosi, and O. B. D. Assis. 2017. Aproveitamento de rejeitos da cadeia hortofrutícula no processamento de plásticos biodegradáveis [Harnessing waste from the horticultural chain in the processing of biodegradable plastics]. *Revista Gestão Industrial* 13:215–29. doi: 10.3895/gi.v13n2.5089.

Barros-Alexandrino, T. T., M. M. Tosi, and O. B. G. Assis. 2019. Comparison between chitosan nanoparticles and cellulose nanofibers as reinforcement fillers in papaya puree films: effects on mechanical, water vapor barrier, and thermal properties. *Polymer Engineering and Science* 59:E287–E292. doi: 10.1002/pen.24938.

Brito, G. F., P. Agrawal, E. M. Araújo, and T. J. A. Mélo. 2011. Biopolímeros, Polímeros Biodegradáveis e Polímeros Verdes [Biopolymers, biodegradable polymers and green polymers]. *Revista*

Eletrônica de Materiais e Processos 6 (2):127–39. http://www2.ufcg.edu.br/revista-remap/index.php/REMAP/article/view/222/204.

Brito, T. B., J. F. Carrajola, E. C. B. A. Gonçalves, M. Martelli-Tosi, and M. S. L. Ferreira. 2019. Fruit and vegetable residues flours with different granulometry range as raw material for pectin-enriched biodegradable film preparation. *Food Research International* 121: 412–21. doi: 10.1016/j.foodres.2019.03.058.

Brito-Nogueira, T. B., T. P. M. Silva, D. Araújo-Luiz, C. J. Andrade, L. M. Andrade, M. S. L. Ferreira, and A. E. C. Fai. 2020. Fruits and vegetable-processing waste: A case study in two markets at Rio de Janeiro, RJ, Brazil. *Environmental Science and Pollution Research International* 27 (15):18530–40. doi: 10.1007/s11356-020-08244-y.

Capitani, M. I., A. Matus-Basto, J. C. Ruiz-Ruiz, J. L. Santiago-García, D. A. Betancur-Ancona, S. M. Nolasco, M. C. Tomás, and M. R. Segura-Campos. 2016. Characterization of biodegradable films based on *Salvia hispanica* L. protein and mucilage. *Food and Bioprocess Technology* 9 (8):1276–86. doi: 10.1007/s11947-016-1717-y.

Cazón, P., G. Velazquez, J. A. Ramírez, and M. Vázquez. 2017. Polysaccharide-based films and coatings for food packaging: A review. *Food Hydrocolloids* 68:136–48. doi: 10.1016/j.foodhyd.2016.09.009.

Comaposada, J., B. Marcos, R. Bou, and P. Gou. 2018. Influence of surfactants and proteins on the properties of wet edible calcium alginate meat coatings. *Food Research International (Ottawa, Ont.)* 108: 539–50. doi: 10.1016/j.foodres.2018.04.002.

Delgado, J. F., M. A. Peltzer, J. R. Wagner, and A. G. Salvay. 2018. Hydration and water vapour transport properties in yeast biomass based films: A study of plasticizer content and thickness effects. *European Polymer Journal* 99:9–17. doi: 10.1016/j.eurpolymj.2017.11.051.

Du, W. X., C. W. Olsen, R. J. Avena-Bustillos, T. H. McHugh, C. E. Levin, and M. Friedman. 2008a. Antibacterial activity against *E. coli* O157:H7, physical properties, and storage stability of novel carvacrol-containing edible tomato films. *Journal* of Food Science 73 (7): 378–83. doi: 10.1111/j.1750-3841.2008.00892.x.

Du, W. X., C. W. Olsen, R. J. Avena-Bustillos, T. H. Mchugh, C. E. Levin, and M. Friedman. 2008b. Storage stability and antibacterial activity against *Escherichia coli* O157:H7 of carvacrol in edible apple films made by two different casting methods. *Journal of Agricultural and Food Chemistry* 56 (9):3082–8. doi: 10.1021/jf703629s.

Du, W. X., C. W. Olsen, R. J. Avena-Bustillos, T. H. Mchugh, C. E. Levin, and M. Friedman. 2009a. Effects of allspice, cinnamon, and clove bud essential oils in edible apple films on physical properties and antimicrobial activities. *Journal of Food Science* 74 (7): M372–378. doi: 10.1111/j.1750-3841.2009.01282.x.

Du, W.-X., C. W. Olsen, R. J. Avena-Bustillos, T. H. McHugh, C. E. Levin, R. Mandrell, and M. Friedman. 2009b. Antibacterial rffects of allspice,garlic, and oregano essential oil sin tomato films determined by overlayand vapor-phase methods. *Journal of Food Science* 74 (7): M390–397. doi: 10.1111/j.1750-3841.2009.01289.x.

Du, W. X., R. j Avena-Bustillos, R. Woods, A. P. Breksa, T. H. McHugh, M. Friedman, C. E. Levin, and R. Mandrell. 2012. Sensory evaluation of baked chicken wrapped with antimicrobial apple and tomato edible films formulated with cinnamaldehyde and carvacrol. *Journal of Agricultural and Food Chemistry* 60 (32):7799–804. doi: 10.1021/jf301281a.

Espitia, P. J. P., R. J. Avena-Bustillos, W.-X. Du, R. F. Teófilo, N. F. F. Soares, and T. H. McHugh. 2014. Optimal antimicrobial formulation and physical–mechanical properties of edible films based on açaí and pectin for food preservation. *Food Packaging and Shelf Life* 2 (1):38–49. doi: 10.1016/j.fpsl.2014.06.002.

Fai, A. E. C., M. R. A. de Souza, S. T. de Barros, N. V. Bruno, M. S. L. Ferreira, and É. C. B. de Andrade Gonçalves. 2016. Development and evaluation of biodegradable films and coatings obtained from fruit and vegetable residues applied to fresh-cut carrot (*Daucus carota* L). *Postharvest Biology and Technology* 112:194–204. doi: 10.1016/j.postharvbio.2015.09.021.

Fakhouri, F. M., S. M. Martelli, T. Caon, J. I. Velasco, and L. H. I. Mei. 2015. Edible films and coatings based on starch/gelatin: Film properties and effect of coatings on quality of refrigerated Red Crimson grapes. *Postharvest Biology and Technology* 109:57–64. doi: 10.1016/j.postharvbio.2015.05.015.

Ferreira, M. S. L., A. E. C. Fai, C. T. Andrade, P. H. Picciani, E. G. Azero, and E. C. B. A. Gonçalves. 2016. Edible films and coatings based on biodegradable residues applied to acerolas (*Malpighia punicifolia* L.). *Journal of the Science of Food and Agriculture* 96 (5): 1634–42. doi: 10.1002/jsfa.7265.

Ferreira, M. S., M. C. Santos, T. M. Moro, G. J. Basto, R. M. Andrade, and E. C. Gonçalves. 2015. Formulation and characterization of functional foods based on fruit and vegetable residue flour. *Journal of Food Science and Technology* 52 (2):822–30. doi: 10.1007/s13197-013-1061-4.

Gonçalves, S. M., D. C. Santos, J. F. G. Motta, R. R. Santos, D. W. H. Chávez, and N. R. Melo. 2019. Structure and functional properties of cellulose acetate films incorporated with glycerol. *Carbohydrate Polymers* 209 (2019):190–7. doi: 10.1016/j.carbpol.2019.01.031.

Jirukkakul, N. 2016. The study of edible film production from unriped banana flour and riped banana puree. *International Food Research Journal* 23 (1):95–101.

Jurgilevich, A., T. Birge, J. Kentala-Lehtonen, K. Korhonen-Kurki, J. Pietikäinen, L. Saikku, and H. Schösler. 2016. Transition towards circular economy in the food system. *Sustainability* 8 (1):69. doi: 10.3390/su8010069.

Lorevice, M. V., M. R. Moura, F. A. Aouada, and L. H. C. Mattoso. 2012. Development of novel guava puree films containing chitosan nanoparticles. *Journal of Nanoscience and Nanotechnology* 12 (3): 2711–7. doi: 10.1166/jnn.2012.5716.

Maniglia, B. C., L. Tessaro, A. P. Ramos, and D. R. Tapia-Blácido. 2019. Which plasticizer is suitable for films based on babassu starch isolated by different methods? *Food Hydrocolloids* 89:143–52. doi: 10.1016/j.foodhyd.2018.10.038.

Martelli, M. R., T. T. Barros, and O. B. G. Assis. 2014. Filmes de polpa de banana produzidos por batelada: Propriedades mecânicas e coloração [Banana pulp films produced by batch: Mechanical properties and coloration. *Polímeros Ciência e Tecnologia* 24 (1):137–42. doi: 10.4322/polimeros.2014.062.

Martelli, M. R., T. T. Barros, M. R. de Moura, L. H. Mattoso, and O. B. G. Assis. 2013. Effect of chitosan nanoparticles and pectin content on mechanical properties and water vapor permeability of banana puree films. *Journal* of Food Science 78 (1):98–104. doi: 10.1111/j.1750-3841.2012.03006.x.

Martucci, J. F., L. B. Gende, L. M. Neira, and R. A. Ruseckaite. 2015. Oregano and lavender essential oils as antioxidant and antimicrobial additives of biogenic gelatin films. *Industrial Crops and Products* 71: 205–13. doi: 10.1016/j.indcrop.2015.03.079.

Matheus, J. R. V., C. J. Andrade, R. F. Miyahira, and A. E. C. Fai. 2020. Persimmon (Diospyros Kaki L.): Chemical Properties, Bioactive Compounds and Potential Use in the Development of New Products – A Review. *Food Reviews International*. doi: 10.1080/87559129.2020.1733597.

McHugh, T. H., and J. M. Krochta. 1994. Water vapor permeability properties of edible whey protein-lipid emulsion films ter vapor permeability properties of edible whey protein-lipid emulsion films. *Journal of the American Oil Chemists' Society* 71 (3):307–12. doi: 10.1007/BF02638058.

McHugh, T. H., and E. Senesi. 2000. Apple wraps: A novel method to improve the quality and extend the shelf life of fresh-cut apples. *Journal of Food Science* 65 (3):480–5. doi: 10.1111/j.1365-2621.2000.tb16032.x.

McHugh, T. H., C. C. Huxsoll, and J. M. Krochta. 1996. Permeability properties of fruit puree edible films. *Journal of Food Science* 61 (1): 88–91. doi: 10.1111/j.1365-2621.1996.tb14732.x.

Moliner, C., K. Aguilar, B. Bosio, E. Arato, and A. Ribes. 2016. Thermo-oxidative characterisation of the residues from persimmon harvest for its use in energy recovery processes. *Fuel Processing Technology* 152:421–9. doi: 10.1016/j.fuproc.2016.07.008.

Monteiro, M., V. Oliveira, F. Santos, E. B. Neto, K. Silva, R. Silva, J. Henrique, and A. Chibério. 2017. Optimization of factors to obtain cassava starch films with improved mechanical properties. *Journal of Physics: Conf. Series* 885:1–5.

Nouraddini, M., M. Esmaiili, and F. Mohtarami. 2018. Development and characterization of edible films based on eggplant flour and corn starch. *International Journal of Biological Macromolecules* 120 (Pt B):1639–45. doi: 10.1016/j.ijbiomac.2018.09.126.

Otoni, C. G., R. J. Avena-Bustillos, H. M. C. Azeredo, M. V. Lorevice, M. R. Moura, L. H. C. Mattoso, and T. H. McHugh. 2017. Recent advances on edible films based on fruits and vegetables — A review. *Comprehensive Reviews in Food Science and Food Safety* 16 (5): 1151–69. doi: 10.1111/1541-4337.12281.

Otoni, C. G., M. R. D. Moura, F. A. Aouada, G. P. Camilloto, R. S. Cruz, M. V. Lorevice, N. D. F. F. Soares, and L. H. C. Mattoso. 2014. Antimicrobial and physical-mechanical properties of pectin/ papaya puree/cinnamaldehyde nanoemulsion edible composite films. *Food Hydrocolloids* 41:188–94. doi: 10.1016/j.foodhyd.2014.04.013.

Parreidt, T. S., M. Schott, M. Schmid, and K. Müller. 2018. Effect of presence and concentration of plasticizers, vegetable oils, and surfactants on the properties of sodium-aginate-based edible coatings. *International Journal of Molecular Sciences* 19 (3):742. doi: 10.3390/ ijms19030742.

Pelissari, F. M., M. M. Andrade-Mahecha, P. J. A. Sobral, and F. C. Menegalli. 2017. Nanocomposites based on banana starch reinforced with cellulose nanofibers isolated from banana peels. *Journal of Colloid and Interface Science* 505 (1):154–67. doi: 10.1016/j.jcis.2017. 05.106.

Peltzer, M. A., A. G. Salvay, J. F. Delgado, and J. R. Wagner. 2017. Use of edible films and coatings for functional foods developments: A review. In *Functional foods sources, health effects and future perspectives*, ed. D. L. Nelson, 1–26. New York: Nova Science Publishers Inc.

Pitak, N., and S. K. Rakshit. 2011. Physical and antimicrobial properties of banana flour/chitosan biodegradable and self sealing films used for preserving Fresh-cut vegetables. *LWT - Food Science and Technology* 44 (10):2310–5. doi: 10.1016/j.lwt.2011.05.024.

Ravishankar, S., D. Jaroni, L. Zhu, C. Olsen, T. McHugh, and M. Friedman. 2012. Inactivation of Listeria monocytogenes on ham and bologna using pectin-based apple, carrot, and hibiscus edible films containing carvacrol and cinnamaldehyde. *Journal* of Food Science 77 (7):377–82. doi: 10.1111/j.1750-3841.2012.02751.x

Reis, L. C. B., C. O. de Souza, J. B. A. da Silva, A. C. Martins, I. L. Nunes, and J. I. Druzian. 2015. Active biocomposites of cassava starch: The effect of yerba mate extract and mango pulp as antioxidant additives on the properties and the stability of a packaged product. *Food and Bioproducts Processing* 94 (2015):382–91. doi: 10. 1016/j.fbp.2014.05.004.

Rojas-Graü, M. A., R. J. Avena-Bustillos, M. Friedman, P. R. Henika, O. Martin-Belloso, and T. H. McHugh. 2006. Mechanical, barrier, and antimicrobial properties of apple puree edible films containing plant essential oils. *Journal of Agricultural and Food Chemistry* 54 (24):9262–7. doi: 10.1021/jf061717u.

Salgado, P. R., C. M. Ortiz, Y. S. Musso, L. Di Giorgio, and A. N. Mauri. 2015. Edible films and coatings containing bioactives. *Current Opinion in Food Science* 5:86–92. doi: 10.1016/j.cofs.2015.09. 004.

Song, Y., and Q. Zheng. 2014. Ecomaterials based on food proteins and polysaccharides. *Polymer Reviews* 54 (3):514–71. doi: 10.1080/ 15583724.2014.887097.

Sothornvit, R., and P. Rodsamran. 2008. Effect of a mango film on quality of whole and minimally processed mangoes. *Postharvest Biology and Technology* 47 (3):407–15. doi: 10.1016/j.postharvbio. 2007.08.005.

Suppakul, P., R. Boonlert, W. Buaphet, P. Sonkaew, and V. Luckanatinvong. 2016. Efficacy of superior antioxidant Indian gooseberry extract incorporated edible Indian gooseberry puree/ methylcellulose composite films on enhancing the shelf life of roasted cashew nut. *Food Control* 69:51–60. doi: 10.1016/j.foodcont. 2016.04.033.

Tulamandi, S., V. Rangarajan, S. S. H. Rizvi, R. S. Singhal, S. K. Chattopadhyay, and N. C. Saha. 2016. A biodegradable and edible packaging film based on papaya puree, gelatin, and defatted soy protein. *Food Packaging and Shelf Life* 10:60–71. doi: 10.1016/j.fpsl. 2016.10.007.

Viana, R. V., N. M. S. M. Sá, M. O. Barros, M. F. Borges, and H. M. C. Azeredo. 2018. Nanofibrillated bacterial cellulose and pectin edible films added with fruit purees. *Carbohydrate Polymers* 196: 27–32. doi: 10.1016/j.carbpol.2018.05.017

Wikström, F., H. Williams, K. Verghese, and S. Clune. 2014. The influence of packaging attributes on consumer behaviour in food-packaging life cycle assessment studies - A neglected topic. *Journal of Cleaner Production* 73:100–8. doi: 10.1016/j.jclepro.2013.10.042.

Zhu, L., C. Olsen, T. McHugh, M. Friedman, D. Jaroni, and S. Ravishankar. 2014. Apple, carrot, and hibiscus edible films containing the plant antimicrobials carvacrol and cinnamaldehyde inactivate Salmonella Newport on organic leafy greens in sealed plastic bags. *Journal* of Food Science 79 (1):61–6. doi: 10.1111/1750-3841.12318.