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Consumer acceptance of fresh-cut peppers and tomatoes and their enhancement by edible coatings

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Abstract

Consumers are increasingly opting for minimally processed vegetables, such as fresh-cut peppers and tomatoes because they are sold in a convenient and ready-to-eat form. Unfortunately, fresh-cut vegetables are susceptible to rapid quality deterioration. Quality is an important term in the agri-food sector and refers to the totality of features and characteristics of a product that are required to satisfy the consumer. The objectives of the study were therefore to (i) shed light on the desirable quality traits of fresh-cut peppers and tomatoes sought by consumers and (ii) assess the effectiveness of edible coatings applied on these vegetables to enhance quality retention. Survey questionnaires were administered to 100 consumers. Quality traits of peppers and tomatoes treated by edible coatings were also assessed. Edible coatings tested were alginate (A), carboxymethyl cellulose (CMC) and xanthan gum (X) which were either left plain or incorporated with potassium sorbate (PS, 0.5% w/v) and/or sodium acetate (SA, 1% w/v). Untreated and treated samples were withdrawn at 3 days' intervals and subjected to microbiological (Total Viable Counts (TVC), Yeast and Mold Counts (YMC)), physicochemical (instrumental colour, moisture content) and sensory (hedonic) analyses. Consumers indicated that the most important attributes when buying fresh-cut peppers and tomatoes were overall appearance, freshness and nutritional value. Surface colour and moisture content values of treated vegetables were comparable to untreated ones throughout refrigerated storage. TVC and YMC for fresh-cut tomatoes coated with X + PS + SA and X + SA were significantly ($P < 0.05$) lower than their untreated counterparts after 9 days of storage. Moreover, the vitamin C content of X + PS + SA-coated fresh-cut peppers (85.8 mg/100g) and tomatoes (3.4 mg/100 g) was higher than for untreated peppers (73.6 mg/100 g) and tomatoes (2.8 mg/100 g) after 9 days of storage. Higher mean appearance and texture scores were also recorded for vegetables treated with X + PS + SA compared with the untreated ones by the end of the storage period. Taken together, the findings of this study point to the effectiveness of xanthan-based antimicrobial edible coatings to enhance consumer-sought quality attributes of fresh-cut peppers and tomatoes.

1. Introduction

Consumption of fresh produce has greatly increased throughout the world due to heightened consumer awareness about healthy eating habits (USDA, 2005; Barth *et al*., 2009). In particular, fresh-cut fruits and vegetables have become popular among consumers because they offer piece size, individual portions, convenience, reduced preparation time and 100% usability of the product (Mitcham *et al*., 1996). Although Mauritius is a developing country, the fresh-cut produce sector is experiencing rapid growth in urbanized regions due to the higher purchasing power and the increasingly busy lifestyle of consumers (Statistics Mauritius, 2019). In addition to fresh-cut vegetables such as broccoli, cabbage and carrots which are widely available commercially (Kader and Saltveit, 2003), peppers and tomatoes are also sold as fresh-cut and widely consumed in salads. According to the literature, consumers are showing an increasing interest in the products they are purchasing and this has an impact on the demand and supply relationship (Wier and Anderson, 2003; Vermeir and Verbeke 2006). Understanding the motivation of consumers for choosing, buying and consuming a certain

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product can help in identifying any barriers to consumption (Popovic *et al.,* 2019). With respect to fresh-cut peppers and tomatoes, there is a need to shed light on the specific desirable characteristics that consumers are in pursuit of.

Unfortunately, fresh-cut peppers and tomatoes have a short shelf life. Due to their soft texture, they can easily be bruised or wounded during post-harvest handling operations such as packaging, transportation and storage (Yahaya and Mardiyya, 2019). These processing operations can also cause damage to the tissues and cellular structure, leading to the leakage of nutrients and cellular fluids (Heard, 2002; Nicola and Fontana, 2014). As a result, fresh-cut peppers and tomatoes provide the ideal environment for the growth of spoilage bacteria and fungi (Brecht *et al*., 2004; Vital *et al.,* 2014). There is no doubt that maintenance of the quality of these minimally processed vegetables is challenging for the food industry.

While there has been significant research on interventions such as modified atmosphere packaging (González-Aguilar *et al*., 2005), ozone treatment (Horvitz and Cantalejo, 2012; Chen *et al*., 2016), sanitisers (Alvarado-Casillas *et al.,* 2007; Ruiz-Cruz *et al*., 2010) and pulsed light treatments (Valdivia-Nájar *et al*., 2018; Kim and Kang, 2018) to delay microbial growth and quality deterioration of fresh-cut peppers and/or tomatoes, there is relatively less work concerning the application of antimicrobial edible coatings on fresh-cut peppers (Saravanakumar *et al*., 2020a, Saravanakumar *et al*., 2000b; Sathiyaseelan *et al*., 2021) or tomatoes (Athmaselvi *et al*., 2013). Edible coatings are semi-permeable barriers that help reduce respiration, retard water loss and colour changes, improve texture and mechanical integrity, improve handling characteristics, help retain volatile flavour compounds, and reduce microbial growth (Huber and Embuscado, 2003). Moreover, lesser research has examined consumer acceptance of these vegetables as affected by the aforementioned treatments. Even if sensory evaluation was carried out, it was usually an after-thought and conducted at the end to verify product acceptance by a panel. Hence, there is a need to first identify the primary attributes affecting consumer preferences for fresh-cut peppers and tomatoes and subsequently assess the effects of edible coatings on these specific attributes. The objectives of this consumer-driven study were therefore to identify specific traits and attributes of fresh-cut peppers and tomatoes which influence consumers' buying choices and preferences and assess whether edible coatings applied on fresh-cut peppers and tomatoes can enhance these attributes.

2. Materials and methods

2.1 Consumer survey

The first part of this investigation consisted of a survey administered to 20 consumers in each of 5 different areas (Northern, North-Western, Southern, Central and Western districts) of Mauritius totalling 100. For the survey, a questionnaire was designed and consisted of two parts: (i) Section A collecting the demographic data of respondents and (ii) Section B identifying the attributes affecting their preferences regarding fresh-cut peppers and tomatoes available at retail outlets.

2.2 Application of edible coatings on fresh-cut peppers and tomatoes

Edible coatings were prepared using hydrocolloids supplied by Sigma-Aldrich without further purification. Other chemicals were supplied by Sigma or Merck. Base coatings were prepared by using Alginate (A), Carboxymethyl cellulose (CMC) and Xanthan gum (X). Different base coating solutions were prepared by dissolving 1.75 g of alginate powder, 3.0 g of CMC powder or 0.2 g of Xanthan gum powder in 100 mL of sterile deionized water on a magnetic stirring hot plate heated to 100°C. Salts of organic acids comprising of PS, SA and SN were added to the different coating bases to achieve final concentrations of 0.5% w/v, 1% w/v and 1% w/v, respectively. A total of 21 treatments (3 coatings × 7 antimicrobial combinations) were prepared during the preliminary trials and applied to fresh-cut peppers and tomatoes. These were subsequently narrowed down to eight treatments (A, A + PS + SA, CMC, CMC + PS, X, X + PS, X + SA, X + PS + SA) based on the characteristics of the coatings and appearance imparted to the vegetables.

Salad peppers (*Capsicum annum* var. Nikita) and tomatoes *(Solanum lycopersicum* var. St Pierre) were obtained from a local supplier and used for this experiment. Peppers and tomatoes that were free from defects and similar in size, colour, shape and degree of maturity were carefully selected. Using flame-sterilized knives, peppers were cut longitudinally in strips (5 cm long × 2 cm wide) weighing ca. 10 g while tomatoes were cut transversely in 0.5 cm-thick discs of similar weight. These were then dipped into the appropriate coating solutions for 2 s and allowed to drain on racks and dry at room temperature for 40 mins in a well-ventilated area. After the coatings had dried, the tomatoes and peppers were packaged in Styrofoam plates wrapped in cling film and stored in the refrigerator at 4°C for 9 days. Untreated peppers and tomatoes that served as control samples were also similarly wrapped in cling film and packaged in Styrofoam and stored for up to 9

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days at 4°C. All samples were stored in the refrigerator and withdrawn at 3 days intervals (Giuffrida *et al*., 2016) for instrumental colour, microbiological, Vitamin C and sensory analyses.

2.3 Analysis of samples

2.3.1 Physicochemical analyses

The colour was determined using a chromameter (Minolta CR-410, Konica Minolta, Japan) and CIE L* and a* values were measured since they give an indication of brightness/lightness and redness to greenness respectively. These colour values are applicable to peppers and tomatoes which vary from green to red as they mature. On the other hand, b values are not reported since blueness to yellowness is not relevant to these samples. Moisture content determination was performed according to official methods of analysis (AOAC, 2000).

2.3.2 Vitamin C content determination

The Vitamin C content of tomato samples was determined by the Indophenol method adapted from AOAC (1999) and Ceirwyn (1995) on Day 0 and Day 9 of refrigerated storage. Briefly, 25 g of each sample was individually ground, weighed, and mixed with 100 mL of 3% metaphosphoric acid-acetic acid solution, and the mixture was subsequently filtered (Neetoo *et al*., 2019). The filtrate was then titrated against indophenol solution until a persistent light pink colour was obtained. The titre values were recorded and the mean was calculated. A blank titration was performed for which the titre value was also recorded. This method was not suitable to determine the vitamin C content in peppers, as it was difficult to see the endpoint of the titration, due to the bright orange colour of the pepper sample. Therefore, a redox titration method using iodine solution was performed (Suntornsuk *et al*., 2002). The endpoint was indicated by a deep blue-black colour.

2.3.3 Microbiological analysis

Pepper strips or tomato slices, weighing approximately 10 g, were aseptically placed in stomacher bags that contained 90 mL of 0.1% w/v sterile buffered peptone water (HiMedia, India) and homogenized for 2 mins at 230 rpm using a stomacher (Seward). The contents of the stomacher bag were then decimally diluted. For each dilution, aliquots of 0.1 mL were plated in duplicate on Plate Count Agar (HiMedia, India) and Potato Dextrose Agar (HiMedia, India) for the enumeration of Total Viable Counts (TVC) (Vanderzant and Splittstosser, 1992) and Yeast and Mold Counts (YMC) (Wigmann *et al.,* 2015), respectively. The plates were then incubated at 35°C for 48 hrs after which the microorganisms were enumerated using a colony counter. Microbiological analysis was carried out at 0, 3, 6 and 9 days through storage. Results were expressed as "log CFU/g".

2.3.4 Sensory analysis

Moreover, a consumer acceptance test was conducted with 10 untrained panellists using a 5-point hedonic scale to assess the liking and disliking of uncoated and coated peppers and tomatoes. An untrained panel was used to be representative of the larger population of naïve consumers as it has been reported to provide more valuable information on the sensory attributes of food (Yang and Lee, 2019). The sensory analysis was performed on Day 0, Day 3, Day 6 and Day 9 of storage. On each day of the analysis, samples were taken out from the fridge and allowed to equilibrate to ambient temperatures (23-25°C) for 30 mins before being presented to the panel on individual opaque white paper plates labelled by letter codes. The sensory parameters tested were overall acceptability, appearance, odour and texture as described by Kondle *et al*. (2019). The sensorial assessment was conducted in a single replicate given the complex logistics associated with a sensory evaluation (Lawless and Heymann, 1998).

2.4 Statistical analysis

Survey data were analysed using Microsoft Excel (Leahy, 2004). All experiments were carried out in at least two independent replicates. All results were analysed using Minitab Release® 17. Data for CIE L*and a* values, moisture and Vitamin C content, sensory scores and microbial population density were analysed using a single-factor ANOVA followed by a Tukey post-hoc test. Statistical significance was attributed to P-values smaller than 0.05 according to the Snedecor and Cochran (1980) procedure.

3. Results and discussion

3.1 Consumer survey

The sample consisted of 51% male and 49% female participants of which 23% were ≤ 25 years of age, 36% were aged between 26 – 35, 24% were in the age group 36 – 45, and 17% between 46 – 65 years of age. The results from the survey gave an insight into the primary drivers that influence consumers' preferences for fresh-cut peppers and tomatoes. The top three most important quality attributes to consumers were overall appearance (92%), nutritional value (94%) and freshness (77%) (Figure 1). Ragaert *et al.* (2004) also analysed the perception of customers concerning minimally processed vegetables and found that the search attribute "product appearance" was significantly more important among consumers in the buying stage. In fact, product

https://doi.org/10.26656/fr.2017.6(6).661

appearance has been referred to as an "intrinsic attribute" that greatly affects consumers' expectations of liking a food (Hurling and Shepherd, 2003). This may explain why Nunes *et al*. (2003) referred to the appearance of fresh vegetables as perhaps the most important factor that determines their market value. The nutritional value of fresh-cut peppers and tomatoes was the second attribute to which the majority of consumers (93%) were most sensitive. Our findings are congruent with those of Zind (1989) and Sillani and Nassivera (2015) who also noted that nutritional value was a decisive factor in buying a product and that consumers placed a greater premium on foods that retain their natural nutritional properties. This is particularly important for fresh-cut vegetables since minimal processing such as peeling (Martin-Belloso *et al*., 2006) and cutting (Kader, 1985; Saltveit, 1997) lead to rapid loss of certain nutrients. Hence a major trade-off with conveniently packed ready-to-eat vegetables is the rapid loss of valuable water-soluble micronutrients. Minimal processing interventions that can guarantee both convenience and nutritional quality are thus widely sought after by consumers. The "Freshness" of fresh-cut peppers and tomatoes was also an important consideration at the time of purchase. Nunes *et al*. (2003) also reported that "freshness" was one of the three most important selection criteria for fresh fruits and vegetables, in addition to ripeness and taste. Contrary to our findings, Cook (1992) identified

Figure 1. Quality traits of fresh-cut peppers and tomatoes sought by consumers at the time of purchase

''taste/flavour'' and ''freshness or ripeness'' slightly above ''appearance/condition'' as factors influencing consumers' purchases of fresh produce.

3.2 The effect of edible coatings on the surface colour of fresh-cut peppers and tomatoes

When assessing quality, consumers take product appearance into consideration as a primary criterion (Garcia and Barrett, 2005). Although appearance can be characterized by size, shape, gloss, condition and absence of defects, product colour is reported to contribute more than any other single factor (Kays, 1999). In fact, consumers expect fresh-cut pieces of vegetables to appear freshly cut, with a bright colour surface (Francis *et al*., 2012). Nunes *et al.* (2003) also indicated that colour is one of the major factors affecting product appearance and also a primary indicator of maturity or ripeness. The surface colour of fresh-cut coated and uncoated peppers and tomatoes was thus determined. The L* values of untreated and treated peppers fell in the range of 46.3 – 47.7 and 45.7 – 48.8 over the 9 days and there was no significant (P > 0.05) change in lightness during storage nor across treatments (Table 1). The a* values of most of the pepper samples, which indicate the degree of redness to greenness, had decreased by the end of the 9-day storage period albeit not significantly (P>0.05). The L* values of treated and untreated tomatoes ranged from 49.9- 53.0 and 45.4 – 52.7 over the 9-day storage period, however, no significant difference (P>0.05) was observed across treatments or during storage (Table 2). Tomatoes treated with CMC and Xanthan gum coatings had slightly higher L* values (51.5-52.7) most likely due to the shiny appearance conferred by the coatings (Athmaselvi *et al.*, 2013). The a* values of untreated and treated tomatoes were not significantly different (P > 0.05) on the last day of the storage period (Table 2). Even though the a* values of CMC+ PS coated tomatoes were highest on Day 0, the values decreased to 15.6 on the 9th day of storage suggesting a decrease in redness intensity. On the

Table 1. L* and a* values of untreated and treated peppers during the 9-day storage period

Treatments	L* values^{ns}				a* values^{ns}			
	Day 0	Day 3	Day 6	Day 9	Day 0	Day 3	Day 6	Day 9
Control	47.2±0.2	47.7±0.4	47.6±0.9	46.3±0.1	18.4±0.2	17.9±0.4	17.4±0.5	18.3±2.0
A	47.9±0.7	47.9±0.4	47.2±0.1	47.0±0.6	19.3±0.2	19.2±0.3	17.3±2.3	19.0±0.4
A + PS + SA	47.5±0.7	47.8±0.3	48.2±0.3	46.6±1.3	17.9±1.0	18.0±1.3	17.0±2.7	18.1±0.5
CMC	46.4±0.5	47.6±0.5	46.7±0.4	46.6±0.9	17.9±0.6	18.0±1.7	16.4±1.6	16.3±2.1
CMC + PS	46.6±0.9	47.9±1.1	47.5±0.8	47.8±0.7	19.2±0.7	17.5±1.3	17.2±1.1	17.0±1.2
X	47.9±0.5	47.7±0.0	47.8±0.4	48.1±0.4	20.1±1.4	20.9±1.7	20.4±0.9	20.2±0.7
X + PS	46.8±1.9	47.7±1.4	47.5±1.7	46.3±1.2	20.2±1.5	18.6±2.0	18.2±1.6	18.2±2.8
X + SA	46.6±0.8	47.9±0.6	47.0±0.4	45.7±1.6	18.7±1.2	17.4±0.8	17.8±0.3	17.6±1.8
X + PS + SA	48.8±1.1	48.6±1.2	48.0±0.7	47.1±0.8	18.9±1.1	17.6±0.9	17.1±1.6	17.4±1.9

Values are mean ± SD of 3 replicates

^{ns}There was no significant difference (P>0.05) in the L* and a* values of peppers among the different treatments within the same day

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Table 2. L* and a* values of untreated and treated tomatoes during the 9-day storage period

Treatments	L* values[ns]				a* values[ns]			
	Day 0	Day 3	Day 6	Day 9	Day 0	Day 3	Day 6	Day 9
Control	52.1±5.7	53.0±5.8	49.9±0.3	52.6±2.8	11.6±2.0	11.4±4.2	11.7±1.9	12.1±3.6
A	49.9±1.1	50.4±1.5	50.6±2.6	52.4±2.0	14.8±5.0	15.2±6.7	14.7±7.0	16.0±6.3
A + PS + SA	50.6±4.1	51.4±4.8	50.1±2.9	52.0±2.5	14.8±5.0	15.2±6.7	14.7±7.0	16.0±6.3
CMC	52.7±1.0	52.0±1.4	50.7±2.1	50.5±6.2	14.6±1.5	13.2±5.6	14.3±3.9	15.2±4.7
CMC + PS	45.4±2.4	49.3±4.2	48.6±1.7	49.0±0.8	20.2±5.4	15.4±6.3	14.6±6.1	15.6±6.6
X	48.7±1.2	48.5±1.5	48.7±0.2	49.6±0.5	11.3±3.2	10.3±0.4	10.4±1.1	11.4±0.5
X + PS	51.5±1.9	50.9±1.4	50.9±1.5	51.6±1.5	14.0±0.9	13.7±1.8	12.6±0.8	14.5±5.5
X + SA	51.7±0.3	50.8±2.6	50.2±3.8	50.2±5.5	13.6±0.7	11.4±4.4	13.5±6.5	14.5±5.8
X + PS + SA	51.2±0.9	52.7±0.1	51.6±0.9	52.0±0.9	13.5±1.2	12.4±6.0	15.3±0.1	13.3±6.4

Values are mean ±SD of 3 replicates

[ns]There was no significant difference (P>0.05) in the L* and a* values of peppers among the different treatments within the same day.

contrary, for most other treatments the a* values increased, ranging from 11.4 - 16.0, possibly due to delayed colour development as also noted by El Ghaouth *et al*. (1992) and Sonti (2003).

3.3 Effect of edible coatings on the moisture content of fresh-cut peppers and tomatoes

Plant tissues are in equilibrium with an atmosphere at the same temperature with a relative humidity of 99 – 99.5% (Gaffney *et al*., 1985) and any reduction of water vapour pressure in the atmosphere below that in the tissue results in water loss (Brecht *et al*., 2004). Accelerated water loss is a major physical problem with fresh-cut peppers and tomatoes due to minimal processing which exposes the hydrated interior tissues and drastically increases the rate of evaporation of water (Brecht *et al*., 2004). Avoiding desiccation at the cut surface of these fresh-cut vegetables is thus critical for maintaining an acceptable visual appearance (Brecht *et al.,* 2004). In addition to serving as an objective indicator for product appearance, moisture content also affects the "freshness" attribute of produce (Lineberry *et al*., 2012). Edible coatings have been demonstrated to control weight loss of fruits and vegetables by acting as effective semi-permeable barriers to solute movement and water vapour transmission (Valencia-Chamorro *et al*., 2008; Mamede *et al*., 2016). In our study, the physiological loss of weight of untreated peppers and tomatoes corresponded with the moisture loss which varied from 0.4-1.6% and 0.3-1.8%, respectively, over the 9-day storage period. For peppers, edible coatings did not appreciably control weight loss as there was no significant (P > 0.05) difference in the moisture content of untreated and treated peppers. Similar results were obtained for tomatoes, except for the A coating, which did significantly control weight loss compared to the control sample on the last day of the storage period. In peppers, the CMC coating resulted in the highest percentage of moisture loss (1.6%) whilst the A+PS+SA coating resulted in the lowest percentage of moisture loss (0.4%) (Table 3). For tomatoes, a similar trend was observed with the highest moisture loss (0.7-1.1%) occurring with plain CMC or X coatings and the lowest moisture loss (0.3%) with X + PS + SA (Table 3). Hence, the role of the different edible coatings in controlling moisture loss was quite variable. The difference in the moisture retention capabilities of X and CMC coatings might be attributed to the chemical structure of xanthan gum which has a higher number of free carboxyl groups than CMC thereby enhancing its water absorption capacity (Aguirre-Cruz *et al*., 2007; Sayanjali *et al.,* 2011). Alginate-based coatings were also found to be effective barriers against water loss by other researchers (Mantilla, 2012; Valero *et al*., 2013; Silva *et al*., 2014). For instance, Senturk Parreidt *et al*. (2018) previously demonstrated that fresh-cut apples coated with alginate-based edible coatings or films underwent lower dehydration due to the coating acting as a sacrificial moisture agent (Rojas-Graü *et al*., 2007). Taken together, surface coatings have the potential to minimize water loss thus contributing to maintaining the product appearance and freshness of minimally processed peppers and tomatoes.

3.4 The effect of edible coatings on the ascorbic acid content of fresh-cut peppers and tomatoes

Nutritionally, peppers and tomatoes represent a good source of vitamins especially Vitamin C (Nunes *et al.,* 2003; Passam *et al*., 2007) and fresh-cut forms of vegetables are thought to meet the consumer demand for healthy food (Francis *et al*., 2012) by virtue of their abundance of vitamins. In addition to serving as an indicator of nutritional quality, studies have shown that Vitamin C is the vitamin that usually degrades most rapidly and can be used as an index of freshness (Howard and Hernandez-Brenes, 1998; Saito *et al*., 2000). In fact, vitamin C or ascorbic acid is a key marker compound for determining the extent of oxidation in fresh-cut vegetables and fruits (Barth *et al.,* 1993a; Barth *et al.,* 1993b). The vitamin C content of untreated

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Table 3. % Moisture loss of peppers and tomatoes after the 9-day storage period

Treatments	Peppers			Tomatoes		
	Moisture content (%w/w)		% moisture loss	Moisture content (%w/w)		% moisture loss
	Day 0	Day 9		Day 0	Day 9	
Control	93.1±0.2^{ab}	92.2±0.1^{ab}	0.9	95.2±0.6^{ab}	93.4±0.5^{bc}	1.8
A	93.4±0.4^{ab}	92.7±0.4^{a}	0.7	96.4±0.1^{a}	96.0±0.1^{a}	0.4
A + PS + SA	93.7±0.5^{a}	93.3±0.7^{a}	0.4	95.3±0.0^{ab}	94.8±0.2^{ab}	0.5
CMC	91.9±0.1^{b}	90.3±0.3^{b}	1.6	94.8±0.7^{b}	94.4±0.5^{bc}	0.4
CMC + PS	92.5±0.8^{ab}	91.8±0.9^{ab}	0.7	94.7±0.3^{b}	94.0±0.5^{bc}	0.7
X	93.2±0.6^{ab}	91.8±0.7^{ab}	1.4	95.9±0.5^{ab}	94.8±0.8^{ab}	1.1
X + PS	93.1±0.2^{ab}	92.0±0.4^{ab}	1.1	94.9±0.2^{b}	93.8±0.7^{bc}	1.1
X + SA	92.9±0.1^{ab}	91.9±0.1^{ab}	0.6	94.4±0.7^{b}	94.0±0.6^{bc}	0.4
X + PS + SA	92.6±0.3^{ab}	91.9±0.4^{ab}	0.7	95.1±0.2^{ab}	94.8±0.3^{ab}	0.3

Values are mean ± SD of 3 replicates. Values with different superscript within the column are significantly different (P<0.05).

peppers was the highest on the first storage day with a value of 115.2 mg/100 g and was comparable to the value of 127.7 mg/100 g reported by Passam *et al.* (2007) for fresh-cut peppers. However, by the end of the 9-day storage period, the vitamin C levels of untreated peppers had declined steeply by 41.6 mg/100 g while xanthan-coated peppers (X, X + PS, X + SA, X + PS + SA) underwent a less drastic loss of 9.9 – 25.6 mg/100 g (Figure 2a). Moreover, peppers coated with plain xanthan (X) had the highest final vitamin C value (87.1 mg/100 g) followed by the treatment X + PS + SA (85.8 mg/100 g) (Table 4). Similarly, for fresh-cut tomatoes, the initial vitamin C level in untreated tomatoes was 10.9 mg/100 g which agrees well with the value of 12.7 mg/100 g reported by Passam *et al.* (2007). However, a steep decline in vitamin C level of untreated and treated fresh-cut tomatoes was noted during storage although the final level in tomatoes coated with X + PS, X + SA and X + PS + SA (3.4 – 4.3 mg/100 g) was still higher than for untreated tomatoes (2.8 mg/100 g) (Figure 2b). Syamal (1991) also noted that the vitamin C content of tomatoes stored for 12 days also tended to decrease during storage (Syamal, 1991). In general, vitamin C degradation is very rapid after harvest and increases as the storage time and temperature increase (Fennema, 1977; Kamper and Fennema, 1985). The rapid loss of vitamin C during storage is not surprising and the rate of ascorbic acid degradation is dependent on various storage parameters including gas composition (Gil *et al.*, 1998; Gil *et al.*, 1999), package design (Barth and Zhuang, 1996), water loss and storage time/temperature (Nunes *et al.,* 1998; Lee and Kader 2000). The reduction in the loss of ascorbic acid in peppers and tomatoes coated with these Xanthan gum treatments can be due to the combined action of Xanthan gum, which acts as a barrier to oxygen, and SA which has antioxidant properties according to Ibrahim Sallam (2007). Similar observations were shown in a study conducted by Sharma and Rao (2015), where the reduction in vitamin C loss in fresh-cut pears was attributed to the synergistic effect of xanthan gum with cinnamic acid. This means that sodium acetate acted as an antimicrobial agent as well as an antioxidant agent. Taken together, it can be inferred that the application of edible coatings contributes towards vitamin C retention and enhances not only the nutritional quality but also the freshness of the vegetables, especially during prolonged storage.

3.5 The ability of edible coatings to control microbial development on fresh-cut peppers and tomatoes

Microbial contamination and growth on fresh-cut vegetables is a major concern for the industry (Nguyen and Carlin, 1994; Hurst, 1995; Beuchat 1996; Fain 1996; Zink 1997) as this can directly limit the shelf-life of fresh -cut vegetables by causing changes in the appearance and/or texture of the products that make them inedible (Brecht *et al.,* 2004). The growth of microorganisms is

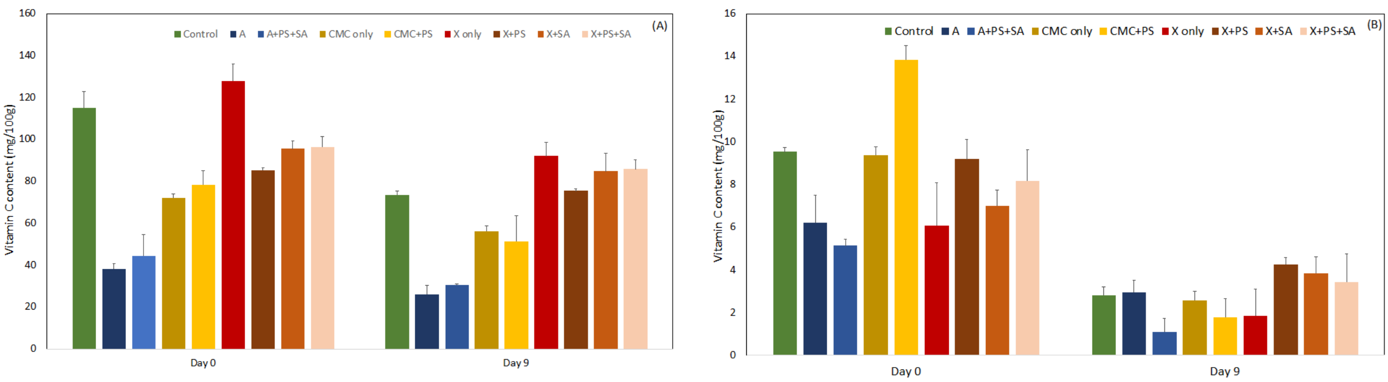

Figure 2. Vitamin C content of fresh-cut (a) peppers and (b) tomatoes treated with the different coatings

Table 4. Total viable counts (TVC) (log CFU/g) of untreated and treated peppers and tomatoes over the 9-days storage period

Treatments	Peppers				Tomatoes			
	Day 0	Day 3	Day 6	Day 9	Day 0	Day 3	Day 6	Day 9
Control	3.14 ± 0.01^{a}	3.16 ± 0.01^{a}	3.21 ± 0.03^{a}	3.18 ± 0.01^{a}	2.85 ± 0.09^{b}	3.16 ± 0.11^{ab}	3.50 ± 0.05^{ab}	3.46 ± 0.73^{ab}
A	3.05 ± 0.09^{a}	3.15 ± 0.06^{a}	3.16 ± 0.02^{ab}	3.18 ± 0.00^{a}	3.96 ± 0.03^{a}	3.95 ± 0.02^{a}	3.98 ± 0.01^{a}	4.05 ± 0.03^{a}
A + PS + SA	2.75 ± 0.04^{ab}	3.05 ± 0.06^{ab}	3.08 ± 0.07^{bc}	3.15 ± 0.01^{ab}	2.68 ± 0.05^{b}	2.59 ± 0.08^{bc}	2.31 ± 0.41^{cd}	2.60 ± 0.48^{bc}
CMC	2.71 ± 0.04^{b}	2.90 ± 0.02^{bc}	2.93 ± 0.01^{cd}	3.04 ± 0.09^{bc}	1.55 ± 0.19^{d}	1.78 ± 0.45^{d}	1.71 ± 0.25^{d}	2.09 ± 0.48^{bc}
CMC + PS	2.69 ± 0.09^{b}	3.01 ± 0.04^{ab}	3.11 ± 0.05^{ab}	3.18 ± 0.04^{a}	1.79 ± 0.10^{cd}	1.88 ± 0.14^{d}	2.06 ± 0.09^{cd}	2.22 ± 0.40^{bc}
X	3.16 ± 0.05^{a}	3.15 ± 0.01^{a}	3.14 ± 0.02^{ab}	3.17 ± 0.02^{ab}	2.60 ± 0.37^{b}	2.77 ± 0.15^{bc}	2.96 ± 0.11^{bc}	2.91 ± 0.25^{bc}
X + PS	2.72 ± 0.19^{b}	3.03 ± 0.02^{ab}	3.02 ± 0.14^{bc}	3.13 ± 0.03^{ab}	2.38 ± 0.21^{bc}	2.66 ± 0.32^{bc}	2.67 ± 0.34^{bc}	2.59 ± 0.12^{bc}
X + SA	2.79 ± 0.08^{ab}	2.93 ± 0.06^{bc}	2.88 ± 0.07^{cd}	2.92 ± 0.01^{cd}	1.69 ± 0.17^{d}	2.17 ± 0.38^{cd}	2.20 ± 0.36^{cd}	1.76 ± 0.18^{cd}
X + PS + SA	2.57 ± 0.05^{b}	2.85 ± 0.06^{c}	2.79 ± 0.04^{d}	2.88 ± 0.00^{d}	1.79 ± 0.10^{cd}	1.98 ± 0.14^{cd}	1.51 ± 0.09^{d}	0.54 ± 0.09^{d}

Values are mean ± SD of 3 replicates Values with different superscript within the column are significantly different (P<0.05).

facilitated by plant cell injury, senescence, or stress (Brecht *et al*., 2004). Common microorganisms directly limiting the shelf-life include pectolytic bacteria (Bartz and Wei, 2003) and fungi (Janisiewicz and Korsten, 2002). Moreover, certain microorganisms indirectly reduce the shelf-life of fresh-cut vegetables through the production of off-flavours, slimes, cloudy plant juices or discolouration (Brecht *et al*., 2004). Given that microbial counts correlate well with the shelf-life of fresh-cut produce (O'Connor-Shaw *et al*., 1994; Watada and Qi, 1999), inhibiting microbial growth can enhance consumer-sought attributes such as freshness and appearance. The initial TVC load of untreated peppers and tomatoes changed from 3.21 and 2.70 log CFU/g on Day 0 to a maximum level of 3.18 and 3.46 log CFU/g, respectively on Day 9. For peppers, treatments such as CMC, X + SA and X + PS + SA did significantly ($P < 0.05$) delay bacterial growth compared to the control, resulting in a TVC load of 3.04, 2.92 and 2.88 log CFU/g, respectively on the last day of the refrigerated storage period (Table 4). Similarly, for tomatoes, treatments such as CMC, X + SA and X + PS + SA also significantly ($P<0.05$) delayed bacterial growth in comparison to the control, resulting in a TVC load of 2.09, 1.76 and 0.54 log CFU/g, respectively at the end of the storage period. For both peppers and tomatoes, X + PS + SA was found to have the greatest bacteriostatic effect, achieving significant ($P < 0.05$) reductions of 0.33 and 2.16 log CFU/g by the end of the storage period (Table 4). Although xanthan gum-based coating did not have an inherent bacteriostatic effect on sliced tomatoes, the incorporation of PS (X + PS) or SA (X + SA) or the combination of both (X + PS + SA) reduced bacterial counts by 0.11, 0.94 and 2.16 log CFU/g respectively after 9 days of storage.

The initial YMC load for untreated peppers and tomatoes changed from 3.17 and 3.46 log CFU/g on Day 0, to 3.14 and 2.34 log CFU/g, respectively on Day 9 (Table 5). The YMC for peppers treated with coatings CMC, X + SA and X + PS + SA ranging from 2.90-2.94 log CFU/g, was significantly ($P < 0.05$) lower than the control sample on the last day of the storage period (Table 5). Similarly, for tomatoes, coatings CMC, X + SA and X + PS + SA also slowed fungal growth attaining maximum counts of 2.09, 1.71 and 0.54 log CFU/g respectively, on the last day of the storage period (Table 5). Coating X + PS + SA had the greatest antifungal effectiveness in both peppers and tomatoes. Overall, xanthan-based coatings can be ranked in the following order of decreasing effectiveness: X + PS + SA > X + SA > X + PS > X. It is possible that the higher effectiveness of xanthan-based coatings compared to alginate or cellulose could be attributed to its high molecular weight. Indeed, xanthan gum favours the building up of physical and chemical networks, which make them ideal carriers of various compounds (Petri, 2015) including preservatives such as SA and PS. The

Table 5. Yeast and mould counts (YMC) (log CFU/g) of untreated and treated peppers and tomatoes over the 9-days storage period

Treatments	Peppers				Tomatoes			
	Day 0	Day 3	Day 6	Day 9	Day 0	Day 3	Day 6	Day 9
Control	3.08 ± 0.04^{a}	3.02 ± 0.04^{a}	2.69 ± 0.47^{a}	3.14 ± 0.05^{ab}	1.43 ± 0.75^{bc}	1.40 ± 0.24^{bc}	2.16 ± 0.05^{ab}	2.34 ± 0.85^{abc}
A	3.10 ± 0.02^{a}	2.99 ± 0.15^{a}	3.12 ± 0.11^{a}	3.18 ± 0.03^{a}	2.52 ± 0.01^{a}	2.52 ± 0.00^{a}	2.59 ± 0.05^{a}	2.86 ± 0.17^{ab}
A + PS + SA	2.43 ± 0.47^{ab}	2.96 ± 0.16^{a}	3.05 ± 0.11^{a}	3.08 ± 0.08^{ab}	0.57 ± 0.38^{c}	1.00 ± 0.22^{c}	1.62 ± 0.05^{b}	2.67 ± 0.11^{abc}
CMC	2.28 ± 0.17^{ab}	2.70 ± 0.04^{a}	2.83 ± 0.09^{a}	2.90 ± 0.07^{c}	1.44 ± 0.41^{bc}	1.57 ± 0.10^{abc}	1.64 ± 0.39^{b}	2.10 ± 0.37^{abc}
CMC + PS	2.61 ± 0.30^{ab}	2.88 ± 0.17^{a}	2.96 ± 0.15^{a}	3.18 ± 0.03^{a}	0.63 ± 0.21^{bc}	1.59 ± 0.30^{abc}	1.50 ± 0.28^{b}	2.32 ± 0.31^{abc}
X	3.16 ± 0.05^{a}	3.16 ± 0.01^{a}	3.13 ± 0.06^{a}	3.17 ± 0.04^{a}	2.25 ± 0.66^{ab}	2.22 ± 0.70^{ab}	2.82 ± 0.08^{a}	2.93 ± 0.10^{ab}
X + PS	2.13 ± 0.06^{b}	2.62 ± 0.32^{a}	2.94 ± 0.15^{aA}	3.19 ± 0.07^{a}	2.27 ± 0.01^{ab}	2.57 ± 0.05^{a}	2.54 ± 0.12^{a}	2.34 ± 0.13^{abc}
X + SA	2.35 ± 0.25^{ab}	2.64 ± 0.30^{a}	2.86 ± 0.06^{a}	2.94 ± 0.03^{bc}	0.50 ± 0.28^{c}	1.30 ± 0.17^{bc}	1.43 ± 0.16^{b}	1.71 ± 0.14^{bc}
X + PS + SA	2.29 ± 0.38^{ab}	2.56 ± 0.29^{a}	2.77 ± 0.04^{a}	2.90 ± 0.06^{c}	0.35 ± 0.49^{c}	0.54 ± 0.09^{c}	0.59 ± 0.16^{c}	1.40 ± 0.11^{c}

Values are mean ± SD of 3 replicates Values with different superscript within the column are significantly different (P<0.05).

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role of edible coatings as carriers of antimicrobials has also been demonstrated by Flores *et al*. (2007) as well as Mehyar *et al*. (2011) who reported that salts of organic acids, such as PS, had higher antimicrobial activity when incorporated into edible coatings (tapioca starch, pea starch, polysaccharide, and guar gum) compared to their direct addition in aqueous solution. Moreover, the successful application of edible coatings incorporating PS has been demonstrated on various other foods including apples, potatoes, and strawberries (Baldwin *et al.,* 1996; Shen *et al*., 2010; Treviño-Garza *et al*., 2015).

The antimicrobial activity of preservatives such as SA and PS has been widely documented in the literature. Costa *et al*. (2014) mentioned that SA acted as an effective food preservative and shelf-life extender. The antimicrobial activity of both SA and PS has been attributed to metabolic inhibition by the undissociated acetic and sorbic acid molecules and to the depression of pH below the growth range for many bacteria (Ibrahim Sallam, 2007). It is also worth mentioning that the enhanced antimicrobial effect of the binary combination of PS and SA observed in our study is in line with the findings of Mendonca *et al.* (1989) and Ukuku and Fett (2004) who noted that it was more efficient to use a combination of antimicrobials than individual treatments. Congruent with our findings, other researchers also reported the synergistic inhibitory effect of PS in combination with other chemicals against several foodborne pathogens (Flores *et al*., 2007; Shen *et al*., 2010; Mehyar *et al*., 2011). For instance, potassium sorbate in combination with benzoates, propionates or acetates has been explored to control bacterial (Kristo *et al*., 2008; Shen *et al*., 2010; Menezes *et al*., 2011) and fungal (Smilanick *et al*., 2008; Montesinos-Herrero, 2009; Mehyar *et al*., 2011) growth. It is possible that the effect could be further enhanced by optimizing the ratio of the two salts. According to several researchers, sodium salts have a significantly higher antimicrobial effect ($P < 0.05$) than potassium salts (Bidlas and Lambert, 2008; Cabezas-Pizarro *et al*., 2018). Taken together, the application of X + PS + SA was found to control bacterial and fungal growth on both fresh-cut peppers and tomatoes, thereby contributing towards quality retention.

3.6 Sensory evaluation of different edible coatings applied on fresh-cut peppers and tomatoes

As indicated by the consumer survey, important considerations in the quality of fresh-cut peppers and tomatoes include a consistent appearance, freshness and nutritional value. According to several researchers (Shewfelt, 1987, Schlimme, 1995; Watada *et al.,* 1996), in addition to a fresh appearance, an acceptable texture of the fresh-cut items is also important. To determine if edible coatings could enhance the consumer-sought attributes of fresh-cut peppers and tomatoes, panellists were asked to evaluate the appearance (Figure 3), texture (Figure 4) and overall acceptability (Figure 5) of coated and uncoated peppers and tomatoes.

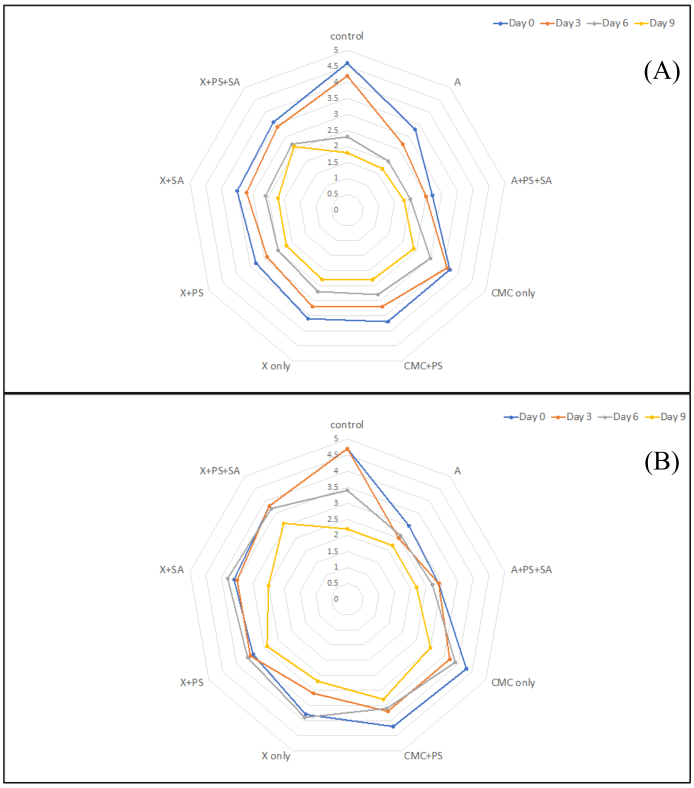

Figure 3. Mean appearance scores of (a) peppers and (b) tomatoes treated with the different coatings over the storage days as determined by untrained panellists (n = 10).

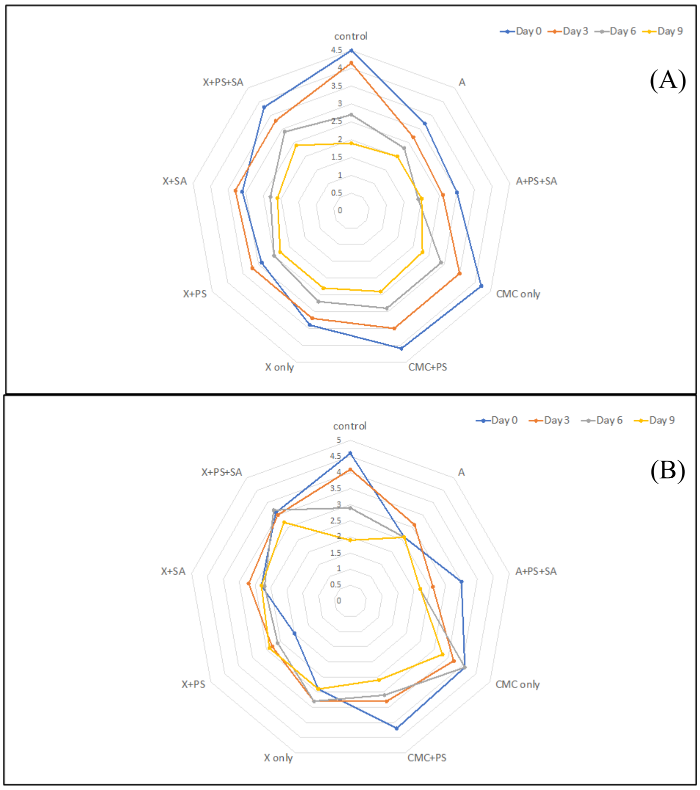

Figure 4. Mean texture scores of (a) peppers and (b) tomatoes treated with the different coatings over the storage days as determined by untrained panellists (n = 10).

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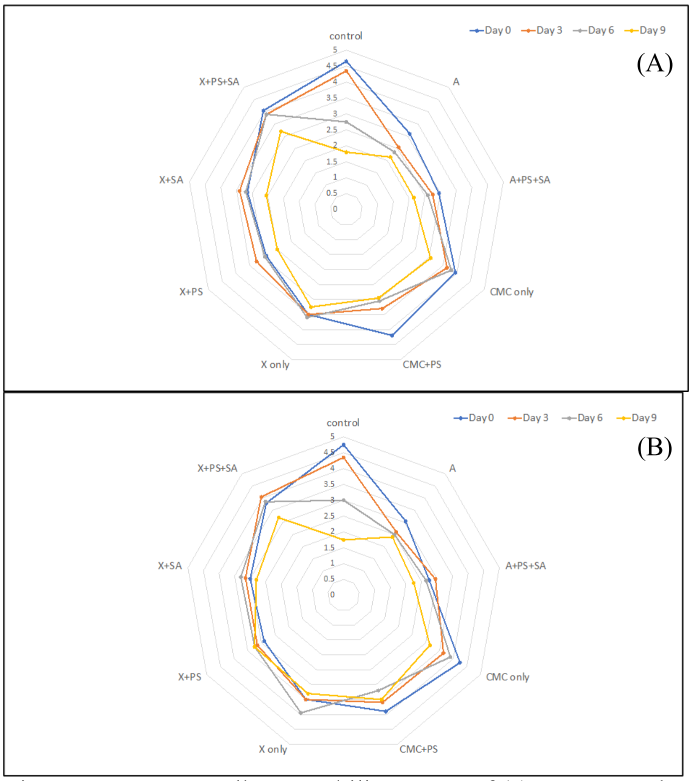

Figure 5. Mean overall acceptability scores of (a) peppers and (b) tomatoes treated with the different coatings over the storage days as determined by untrained panellists (n = 10).

The initial scores for the overall acceptability of uncoated peppers and tomatoes, on a scale of 1-5, were 4.7 and 4.8 respectively, while the scores for treated peppers and tomatoes varied from 2.9 - 4.2 and 2.8 - 4.3 depending on the coating formulation. However, the scores for both untreated peppers (Figure 5a) and tomatoes (Figure 5b) drastically decreased to 1.8 after 9 days of storage. Scores for A and A + PS + SA coated peppers and tomatoes had the lowest overall scores on the final day of storage with 2.2 and 2.2 and 2.4 and 2.3, respectively compared to the other coating treatments. For peppers, X and X + PS + SA coated peppers earned the highest final scores on the last day of storage with 3.3 and 3.2, respectively. For tomatoes, CMC + PS, X and X + PS coated tomatoes earned the highest final scores on the final day of storage with 3.5, 3.3 and 3.3, respectively. With respect to texture, for both peppers and tomatoes, initial ratings were highest for the untreated vegetables (4.5 - 4.6) but declined rapidly to 1.9 by the end of the storage period. A similar trend was observed for coated vegetables although the final texture scores for peppers and tomatoes coated with CMC or X + PS + SA were still higher than their untreated counterparts after 9 days. Taken together, we can infer that the application of xanthan coatings incorporating PS and SA had a minimal negative impact on the appearance, texture and overall acceptability of the fresh-cut peppers and tomatoes. Freitas *et al.* (2013) and Sharma and Rao (2015) also noted that xanthan gum was a good carrier of antimicrobials when applied to fresh-cut apples and pears respectively with a minimal adverse effect on the sensorial acceptability.

4. Conclusion

The quality of fresh-cut peppers and tomatoes is a combination of attributes, properties, or characteristics that determine their value to the consumer (Kader, 2002). The most important quality parameters identified by the consumers at the time of purchase were "appearance", "freshness" and "nutritive value". This study compared the ability of three polysaccharide-based antimicrobial coatings, incorporating selected GRAS agents, to enhance these quality attributes in fresh-cut peppers and tomatoes. The findings revealed that during the first three days of storage, uncoated peppers and tomatoes surpassed their treated counterparts in terms of appearance, texture and overall acceptability. However, with prolonged storage, it was observed that xanthan-based antimicrobial coatings conferred an advantage to coated fresh-cut peppers and tomatoes by helping to maintain the appearance, surface colour, freshness, moisture, texture, Vitamin C content as well as microbial quality. Taken together, xanthan gum supplemented with salts of organic acids has the potential to enhance several of the attributes sought after by customers of fresh-cut vegetables. Future studies will investigate the effect of the addition of antioxidants, fungicides, and vitamins to the hydrocolloid mix on the coating performance as well as the nutritional value of the fresh-cut products. Moreover, the effect of the coatings on the titratable acidity and textural properties of treated peppers and tomatoes also need to be ascertained before the eventual commercial application of the coatings.

Conflict of interest

The authors declare that there is no conflict of interest.

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