Development of antimicrobial edible coating based on modified chitosan for the improvement of strawberries shelf life

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Abstract Edible antimicrobial coating produced from chitosan (CS) and its derivative was applied to improve the shelf life of fresh strawberries at 10 °C. Fruits treated with coating solution was stored at 10 °C and evaluated for weight loss, visual decay and microbiological analysis. Results indicated that the percentage weight loss and the decay were significantly ($p < 0.05$) lower for chitosan-monomethyl fumaric acid (CS-MFA) than that of CS and control samples. The total aerobic count for CS-MFA was 3.32 log CFU/fruit and was considerably lowered ($p < 0.05$) than CS (3.83 log CFU/fruit) and control (5.31 log CFU/fruit) at the end of storage. Fruit coated with CS-MFA showed significantly lowered ($p < 0.05$) count of yeast and molds when compared with CS. In conclusion, the antimicrobial edible coating based on modified CS improved microbiological characteristics and increased the shelf life from 4 (control) to 8 days (coated fruits).

Keywords Edible coating · Chitosan derivatives · Strawberries · Shelf life

Introduction

Fresh strawberries are highly perishable, nonclimacteric fruit, highly valued for its organoleptic properties. They have a very fast ripening stage because of high respiration and softening rate, smooth texture, and high sensitivity to fungal attack (Nadim et al., 2015). Strawberries are very popular berry and famous for its desirable flavor and antioxidant properties (high vitamin C and anthocyanins) (Pineli et al., 2015). The main changes in fruit composition which are usually associated with ripening, take place when the fruit is still attached to the mother plant (Mirahmadi et al., 2012). Therefore, the quick consumption of the fruit right after harvesting is just due to its short life (Cordenunsi et al., 2003). The shelf life is mainly governed by maturity during harvesting and postharvest conditions that could lead to the changes in nutritional and sensory qualities. Strawberries are usually harvested at three-fourths ripe (pink) or even one-half ripe (green) stages, in order to avoid postharvest losses due to softening and fungal deterioration. However, the ripening of strawberries is a major issue during harvesting as it directly influences the quality and antioxidant properties (Pineli et al., 2011). Still, the quality maintenance of strawberries such as color, flavor, texture, appearance, nutritional value and microbial safety is a major challenge for the food industry (Nadim et al., 2015). Throughout the production of strawberry fruits, the chances for contamination exists due to inappropriate sanitation, contaminated pickers and irrigation water, and manure fertilized fields (Bialka and Demirci, 2008; Han et al., 2004b).

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To maintain the quality of fresh strawberries, food industry has adopted various interventional technologies including edible coating. Edible coating has been extensively used for fresh fruits in order to prevent it from physical and mechanical damages, microbial spoilage, loss of quality and foodborne pathogens (Peretto et al., 2017). Edible coatings are environmentally friendly and they can serve as carriers of food additives that improve nutritional, safety, and sensory attributes of fruit (Tapia et al., 2008).

Chitosan (CS) is naturally obtained polysaccharide, has shown to have excellent antioxidant and antimicrobial activity (Khan et al., 2015; Khan et al., 2016). CS has been utilized as an edible coating material for various fruits (Chien et al., 2007; Jiang and Li, 2001; Kerch, 2015; Petriccione et al., 2015; Zhang and Quantick, 1997). However, researchers around the world are trying to modify CS to enhance its solubility (water at neutral pH, organic solvent) and functional properties (antimicrobial and antioxidant activity etc.) (Jiang et al., 2014; Khan et al., 2016; Severino et al., 2015; Wang et al., 2015). Previously CS was modified with monomethyl fumaric acid (MFA) to enhance its solubility and antimicrobial activity (Khan et al., 2016). In another study, the effectiveness of edible antimicrobial coating on beef meat under refrigeration storage for 2 weeks was studied and the results indicated that shelf life of meat was enhanced by about 8 days (Khan et al., 2017a).

The aim of the current study was to develop enhanced antimicrobial coating by modifying CS with MFA and characterized by Fourier-transform infrared spectroscopy (FT-IR) and the degree of amino group substitution by TNBS assay. The efficacy of antimicrobial edible coating based on modified CS on the shelf life of fresh strawberries for 8 days was studied and compared with CS (Fig. 1).

Materials and methods

Modification of chitosan

CS was modified by MFA using 1-ethyl-3-(3-dimethylaminopropyl) carbodiimide (EDC) as mediator as described by Khan et al. (2016) with little modifications. CS (MW = 52 kDa; Sigma Aldrich, St. Louis, MO, USA) was dissolved in 1% acetic acid solution and kept overnight at room temperature under continuous stirring to get homogenous solution. The pH of CS solution was maintained at around 6.0 using 1 molar NaOH solution. MFA (Sigma Aldrich, St. Louis, MO, USA) at 1% concentration was dissolved in 50 ml aqueous solution and subsequently added to EDC (1%; Sigma Aldrich, St. Louis, MO, USA) and stirred for 1 h to activate the carboxylic group. Then, MFA/EDC solution was slowly added to CS solution and

maintained the pH at 6.0 using NaOH solution. The reaction mixture was stirred for 18 h at room temperature. The reaction solution was dialyzed using dialysis membrane (MWCO: 12–14 kDa; Membrane Filtration Products, Inc. USA) to remove any unbound reagents against distilled water (DW) for 72 h. The reaction solution was frozen at -80°C for 24 h and then freeze dried (LabTech, Daihan LabTech Co. Ltd., Korea) at 0.05 mTorr and $-45 \pm 1^{\circ}\text{C}$ for 72 h. After freeze drying, the synthesized CS-MFA was characterized for % substitution of amino group of CS according to procedure previously described by Hardiansyah et al. (2015). The modification of CS with MFA was confirmed by FT-IR analysis using Perkin–Elmer Frontier FT-IR spectrometer instrument (Perkin–Elmer, Waltham, MA, USA) and all the samples were prepared as KBr pellet and scanned against a blank KBr pellet background at wave number range $4000\text{--}400\text{ cm}^{-1}$ with resolution of 4.0 cm^{-1} . The modified polymer was stored at 4°C for further experiments.

Preparation of coating solutions

The edible coating solution was prepared by dissolving 1% CS or CS-MFA in diluted HCl (pH = 2.8). The solution was stirred until clear solution of CS and CS-MFA was obtained. The pH of both solutions was adjusted to 5.0 using 1 M NaOH solution.

Strawberries preparation and storage conditions

Fresh ‘Seolhyang’ strawberries were obtained from Lotte Mart, Chuncheon, Gangwon-do, Korea. Strawberries were brought in temperature controlled environment and kept at 4°C for experimental use. Strawberries were used in the experiment on same day to avoid any spoilage. Strawberries were selected for the experiment on the basis of uniform size, weight, color and absence of physical or pathological damage and placed in a plastic rack. Strawberries were washed carefully using tap water and kept in a clean bench for an hour to dry. Strawberries were dipped in CS and CS-MFA solution for 5 min to ensure uniform coating over the fruits. Strawberries were air dried inside the clean bench for 1 h. A total of 30 coated and uncoated strawberries were kept individually in a stomacher bag (Nasco Whirl–Pak, Janesville, WI, USA) at 10°C ($\pm 0.5^{\circ}\text{C}$), 90% relative humidity for 8 days. All treatments including uncoated (negative control) were tested immediately after coating (day 0), and at 2, 4, 6 and 8 days of storage. The experiment is repeated twice.

Fig. 1 Schematic representation of chitosan-monomethyl fumaric acid synthesis and edible coating for fresh strawberries for 8 days of storage at 10 °C

Visual decay and weight loss of strawberries

Strawberries were examined every day and considered as spoiled if a visible lesion observed, characterized as brown spot of the infected area. The results were expressed as percentage of spoiled fruits based on the total number of fruits. Weight loss of the strawberries was expressed as percentage loss based on initial weight measured after coating. Weight loss of the strawberries was calculated as follows:

$$\text{Weight loss(\%)} = \left(A - \frac{B}{A} \right) 100$$

where A is initial weight of the strawberry and B is the final weight of the strawberry.

Microbiological analysis

About 24 ml of 0.1% buffered peptone water (BPW; Difco, Sparks, MD, USA) were added to coated and uncoated samples. Then the samples were stomached for 2 min using Seward stomacher (400 Circulator, Seward, London, UK). All the samples were serially diluted in BPW and surface plated on agar media in duplicate. For naturally occurring microorganisms, tryptic soy agar (TSA; Difco, Sparks, MD, USA) plates were used to enumerate the total aerobic bacteria. TSA plates were kept after bacterial spreading at

37 °C for 24 h. Dichloran Rose Bengal Chloramphenicol Agar (DRBC) was used to enumerate yeast and molds (YM). DRBC plates were kept at 25 °C for 48 h.

Statistical analysis

The data were analyzed by one-way ANOVA SPSS software (IBM SPSS version 21.0; IBM Corp, Chicago, USA) and expressed as mean $\pm$ standard deviation. Tukey's multiple range tests were used to determine the significant differences at $p < 0.05$ between different treatments.

Results and discussion

Synthesis and characterization of chitosan derivative

The attachment of MFA to CS was carried out using a 75–85% deacetylated CS in the presence of EDC at pH 6.0. EDC activated the carboxylic group on MFA before added to CS solution. MFA was covalently attached to CS through the formation of amide linkage between the carboxylic group of MFA and amino group of CS as previously described (Khan et al., 2016; Wang et al., 2015). The attachment of MFA to CS was confirmed by TNBS assay and FT-IR analysis. The TNBS assay showed that

Fig. 2 FT-IR spectroscopy analysis of chitosan (CS) and modified chitosan with monomethyl fumaric acid (CS-MFA). The FT-IR spectrum shows all the characteristic peaks of modified CS

$7.23 \pm 0.03\%$ of amino group was substituted by MFA after 18 h of reaction time. The FT-IR analysis showed all the characteristics spectra of conjugated CS with MFA. As shown in Fig. 2, the spectrum of CS exhibit a broad band at 3429.83 cm^{-1} accredited to $-\text{NH}$ and $-\text{OH}$ stretching vibration of CS, while the bands at 1653, 1594.88, and 1322 cm^{-1} were accredited to the amide one, the amine $-\text{NH}_2$ and amide three absorption of CS, respectively (Da Róz et al., 2011; Khan et al., 2016; Zhang et al., 2003). The FT-IR spectrum of CS-MFA showed a characteristic band at 1712 cm^{-1} , which was accredited the absorption band of carbonyl ester in MFA. The FT-IR spectra of CS-MFA revealed all the characteristics peaks of CS conjugate (Khan et al., 2016).

Shelf life of strawberries

Changes in weight loss and visual decay

In order to determine the effectiveness of antimicrobial coating for enhancing the quality of fresh strawberries, weight loss and visual decay as primary determinants of quality were observed every second day during the storage time and statistically compared to uncoated (control) samples. Generally, weight loss is linked to moisture evaporation and respiration on the fruit's surface (Aday and Caner, 2011). The weight loss of strawberries is occurred when moisture contents evaporate from the fruit surface to the surrounding atmosphere. The effect of coated and uncoated samples on the % weight loss of strawberries is depicted in Fig. 3. Coating significantly reduced ($p < 0.05$) weight loss of strawberry throughout storage. Data indicated that the % loss of all the treatment increased with increasing storage period. The highest % weight loss

was observed for control sample of 2.02% at the end of storage and significantly different ($p < 0.05$) when compared to coated samples. However, there was no significant difference ($p > 0.05$) was observed between CS and CS-MFA and the % loss for both treated samples were remained the same with 1.43 and 1.37% weight loss, respectively at the end of storage. Previous studies also showed similar results for CS coating that CS coating formed on the surface of the fruit delayed transfer of moisture contents from the fruit into the surrounding environment, consequently reducing weight loss (Garcia et al., 1998; Han et al., 2004a; Vu et al., 2011).

Visual fungal decay (Fig. 4A, B) started quickly on the control samples, with 5% of strawberries displaying sign of infection after 4 days of storage and 11% after two additional days of storage at 10°C . The infection rate increased with increasing storage time, recorded 21% infection at the end of storage and significantly higher ($p < 0.05$) as compared to the controlled samples. CS and CS-MFA coated samples started to show first signs of decay at day 6, showing 28% less spoilage than control samples. The 2 days of spoilage decay observed for CS and CS-MFA coated samples over control may have important economic implications, as the shelf life of fruits can be extended in the fresh market. Moreover, at the end of storage, CS-MFA significantly ($p < 0.05$) reduced the spoilage when compared to CS coated samples. The CS-MFA coating treatment significantly inhibited strawberry decay with 5% of spoiled fruits, compared to 10 and 21% for CS and control samples after 8 days of storage, respectively. The antimicrobial CS and CS-MFA coating has shown to have great potential in reducing strawberries decay for extended period of time. Ghaouth et al. (1991), reported that CS (1 and 1.5%) coating significantly ($p < 0.05$) inhibited the decay of strawberries as compared to the control with no significant difference between CS and fungicide treatments up to 21 days of storage at 13°C . However, strawberries stored at 4°C exhibited good qualities as compared to strawberries stored at 13°C . These results suggested that CS concentration and storage temperature has direct impact on strawberries quality and shelf life. In another study, Gol et al. (2013) studied the quality and shelf-life of strawberries coated with edible CS composites at 11°C for 12 days. Results indicated that test samples exhibited significant delays in the change of weight loss, titratable acidity, decay percentage, pH, ascorbic acid contents and total soluble solids as compared to control samples. Contrary to our findings, the percentage decay of strawberries was higher for all the test samples including control. The difference in the finding can be attributed to the storage temperature.

Fig. 3 Percentage weight loss of strawberries during storage time at 10 °C after coated with antimicrobial edible film. *CS* chitosan, *CS-MFA* chitosan modified with monomethyl fumaric acid. Different letters *a–b* indicates significant differences among treatments during storage period at $p < 0.05$

Fig. 4 Percentage visual decay of strawberries during storage time at 10 °C after coated with antimicrobial edible film and uncoated (control) (A) and images of strawberries during experiment (B). *CS* chitosan, *CS-MFA* chitosan modified with monomethyl fumaric acid. Different letters *a–c* indicates significant differences among treatments during storage period at $p < 0.05$

Microbiological analysis

CS has already shown good antimicrobial activity against a broad spectrum of microorganisms (Khan et al., 2015; Khan et al., 2016; Khan et al., 2017a; 2017b). Therefore, CS and its derivatives could be utilized as edible antimicrobial coating for fresh strawberries in order to control spoilage microorganisms, and thus increased the shelf life. As shown in Fig. 5, as soon as antimicrobial coating was applied, the level of microorganisms was reduced ($p < 0.05$). Studies showed that fruits treated with antimicrobials produce strong barriers against microbial contamination when compared to control (Mali and Grossmann, 2003; Tamer and Çopur, 2010; Treviño-Garza et al., 2015). The CS-MFA was the most effective in reducing initial microbial growth. Moreover, the growth of microbes increased ($p < 0.05$) throughout storage period especially in control (2.43 and 5.3 log CFU/fruit), followed by CS (2.25 and 3.83 log CFU/fruit) and CS-MFA (2.02 and 3.32 log CFU/fruit). The TAC for CS was significantly ($p < 0.05$) lower than control and higher than CS-MFA throughout the storage. Previous study showed that edible coating based on CS was more active ($p < 0.05$) in controlling TAC as compared to control and other tested samples (Treviño-Garza et al., 2015). The effect of CS-MFA on controlling TAC was prominent ($p < 0.05$) throughout storage as compared to control and CS samples. The increased effectiveness of CS-MFA could be attributed to the functional group MFA, attached to the backbone of CS. Previous studies showed that MFA improved the antimicrobial and antioxidant activity of CS along with

increasing solubility (Khan et al., 2016; Wang et al., 2015; Xia et al., 2011).

The count of YM is an important parameter in the quality determination of fresh fruits and vegetables. The effect of CS and CS-MFA coating on YM count was determined and depicted in Fig. 6. Strawberries are usually highly susceptible to fungal infection and therefore the shelf life is comparatively short. Immediately after the coating was applied (day 0), the level of YM was reduced ($p < 0.05$). This could be explained by the fact that CS has the potential to interact with the negatively charged phospholipid materials of fungi membrane, increased the permeability of membrane and causes leakage of cellular materials and ultimately leads to death (Ing et al., 2012; Liu et al., 2004). It was found that the count of YM was increased ($p < 0.05$) specifically for control (2.34 and 6.49 log CFU/fruit) and in strawberries coated with antimicrobials (2.26 and 5.28 log CFU/fruit for CS and 2.22 and 5.04 log CFU/fruit for CS-MFA). This increase in the growth of YM can be explained by the fact that strawberries are prone to high levels of YM pathogen contamination compared to other fruits because they possess: (1) high levels of sugars and nutrients; (2) optimal water activity and pH for fungal growth; and (3) a soft skin that can be easily ruptured for microorganisms to proliferate (Junqueira-Gonçalves et al., 2017; Vu et al., 2011). CS-MFA was effectively ($p < 0.05$) control the count of YM when compared to the counterpart CS and control throughout the storage. After the day 08, the differences between coated and uncoated samples are greater than one log cycle, exhibiting that antimicrobial coatings based on CS-MFA

Fig. 5 Survival of total viable count (TVC) on strawberries during storage time at 10 °C after coated with antimicrobial edible film and uncoated (control). CS chitosan, CS-MFA chitosan modified with monomethyl fumaric acid. Different letters *a–c* indicates significant differences among treatments during storage period at $p < 0.05$

Fig. 6 Survival of yeast and molds (YM) on strawberries during storage time at 10 °C after coated with antimicrobial edible film and uncoated (control). CS chitosan, CS-MFA chitosan modified with monomethyl fumaric acid. Different letters *a–c* indicates significant differences among treatments during storage period at $p < 0.05$

and CS are effective in controlling postharvest contamination. Our findings are in agreement with previous studies where antimicrobial coating effectively controlled YM count throughout storage (Junqueira-Gonçalves et al., 2017; Nasrin et al., 2017; Treviño-Garza et al., 2015; Valenzuela et al., 2015). It is known that CS-based antimicrobial coating possess a protective effect against YM growth on fresh fruits and vegetables (Vu et al., 2011). According to Mazur and Waksmundzka (2001), the treatment of CS solution on strawberries had a protective effect and effectively reduced the percentage decay by about 15%. However, still the effect of modified CS coating on strawberries for increasing the shelf life is not mentioned elsewhere.

Hence, the application of CS-MFA appears to be highly promising in the field of food processing for extending the shelf life of strawberries during storage. Further studies are required to optimize the modification of CS and their activity to be used as coating material in the food industry.

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References

- Aday MS, Caner C. The applications of 'active packaging and chlorine dioxide' for extended shelf life of fresh strawberries. *Packag. Technol. Sci.* 24: 123–136 (2011)
- Bialka KL, Demirci A. Efficacy of pulsed uv-light for the decontamination of *Escherichia coli* O157:H7 and *Salmonella* spp on

- raspberries and strawberries. *J. Food Sci.* 73: M201–M207 (2008)
- Chien P-J, Sheu F, Yang F-H. Effects of edible chitosan coating on quality and shelf life of sliced mango fruit. *J. Food Eng.* 78: 225–229 (2007)
- Cordenunsi B, Nascimento JD, Lajolo F. Physico-chemical changes related to quality of five strawberry fruit cultivars during cool-storage. *Food Chem.* 83: 167–173 (2003)
- Da Róz AL, Zambon MD, Curvelo AA, Carvalho AJ. Thermoplastic starch modified during melt processing with organic acids: The effect of molar mass on thermal and mechanical properties. *Ind. Crops Prod.* 33: 152–157 (2011)
- Garcia MA, Martino MN, Zaritzky NE. Plasticized starch-based coatings to improve strawberry (*Fragaria × ananassa*) quality and stability. *J. Agric. Food Chem.* 46: 3758–3767 (1998)
- Ghaouth A, Arul J, Ponnampalam R, Boulet M. Chitosan coating effect on storability and quality of fresh strawberries. *J. Food Sci.* 56: 1618–1620 (1991)
- Gol NB, Patel PR, Rao TVR. Improvement of quality and shelf-life of strawberries with edible coatings enriched with chitosan. *Postharvest Biol. Technol.* 85: 185–195 (2013)
- Han C, Zhao Y, Leonard SW, Traber MG. Edible coatings to improve storability and enhance nutritional value of fresh and frozen strawberries (*Fragaria × ananassa*) and raspberries (*Rubus idaeus*). *Postharvest Biol. Technol.* 33: 67–78 (2004a)
- Han Y, Selby T, Schultze K, Nelson P, Linton RH. Decontamination of strawberries using batch and continuous chlorine dioxide gas treatments. *J. Food Protect.* 67: 2450–2455 (2004b)
- Hardiansyah A, Huang L-Y, Yang M-C, Purwasasmita BS, Liu T-Y, Kuo C-Y, Liao H-L, Chan T-Y, Tzou H-M, Chiu W-Y. Novel pH-sensitive drug carriers of carboxymethyl-hexanoyl chitosan (Chitosonic® Acid) modified liposomes. *RSC Adv.* 5: 23134–23143 (2015)
- Ing LY, Zin NM, Sarwar A, Katas H. Antifungal activity of chitosan nanoparticles and correlation with their physical properties. *Int. J. Biomater.* (2012). <https://doi.org/10.1155/2012/632698>
- Jiang Y, Li Y. Effects of chitosan coating on postharvest life and quality of longan fruit. *Food Chem.* 73: 139–143 (2001)

- Jiang H-L, Cui P-F, Xie R-L, Cho C-S. (2014) Chemical modification of chitosan for efficient gene therapy. *Adv. Food Nutr. Res.* 73: 83–101
- Junqueira-Gonçalves MP, Salinas GE, Bruna JE, Niranjana K. An assessment of lactobiotopolymer-montmorillonite composites for dip coating applications on fresh strawberries. *J. Sci. Food Agric.* 97: 1846–1853 (2017)
- Kerch G. Chitosan films and coatings prevent losses of fresh fruit nutritional quality: A review. *Trends Food Sci. Technol.* 46: 159–166 (2015)
- Khan I, Khan M, Umar MN, Oh D-H. Nanobiotechnology and its applications in drug delivery system: a review. *IET Nanobiotechnology* 9: 396–400 (2015)
- Khan I, Ullah S, Oh D-H. Chitosan grafted monomethyl fumaric acid as a potential food preservative. *Carbohydr. Polym.* 152: 87–96 (2016)
- Khan I, Tango CN, Miskeen S, Oh D-H. Evaluation of nisin-loaded chitosan-monomethyl fumaric acid nanoparticles as a direct food additive. *Carbohydr. Polym.* 184: 100–107 (2017a)
- Khan I, Tango CN, Oh DH. Development and evaluation of chitosan and its derivative for the shelf life extension of beef meat under refrigeration storage. *Int. J. Food Sci. Technol.* 52: 1111–1121 (2017b)
- Liu H, Du Y, Wang X, Sun L. Chitosan kills bacteria through cell membrane damage. *Int. J. Food Microbiol.* 95: 147–155 (2004)
- Mali S, Grossmann MVE. Effects of yam starch films on storability and quality of fresh strawberries (*Fragaria ananassa*). *J. Agric. Food Chem.* 51: 7005–7011 (2003)
- Mazur S, Waksmondzka A. Effect of some compounds on the decay of strawberry fruits caused by *Botrytis cinerea* Pers. Mededelingen (Rijksuniversiteit te Gent. Fakulteit van de Landbouwkunde en Toegepaste Biologische Wetenschappen) 66: 227–231 (2001)
- Mirahmadi F, Hanafi QM, Mohammadi H. Effect of low temperatures on physico-chemical properties of different strawberry cultivars. *ARPJ. Agric. Biol. Sci.* 7: 564–569 (2012)
- Nadim Z, Ahmadi E, Sarikhani H, Amiri Chayjan R. Effect of methylcellulose-based edible coating on strawberry fruit's quality maintenance during storage. *J. Food Process. Preserv.* 39: 80–90 (2015)
- Nasrin T, Rahman M, Hossain M, Islam M, Arfin M. Postharvest quality response of strawberries with aloe vera coating during refrigerated storage. *J. Hortic. Sci. Biotechnol.* 92: 598–605 (2017)
- Peretto G, Du W-X, Avena-Bustillos RJ, Berrios JDJ, Sambo P, McHugh TH. Electrostatic and conventional spraying of alginate-based edible coating with natural antimicrobials for preserving fresh strawberry quality. *Food Bioprocess. Technol.* 10: 165–174 (2017)
- Petriccione M, De Sanctis F, Pasquariello MS, Mastrobuoni F, Rega P, Scortichini M, Mencarelli F. The effect of chitosan coating on the quality and nutraceutical traits of sweet cherry during postharvest life. *Food Bioprocess. Technol.* 8: 394–408 (2015)
- Pineli LLO, Moretti CL, dos Santos MS, Campos AB, Brasileiro AV, Córdova AC, Chiarello MD. Antioxidants and other chemical and physical characteristics of two strawberry cultivars at different ripeness stages. *J. Food Compos. Anal.* 24: 11–16 (2011)
- Pineli LdLo, Moretti CL, Chiarello M, Melo L. Influence of strawberry jam color and phenolic compounds on acceptance during storage. *Revista Ceres* 62: 233–240 (2015)
- Severino R, Ferrari G, Vu KD, Donsi F, Salmieri S, Lacroix M. Antimicrobial effects of modified chitosan based coating containing nanoemulsion of essential oils, modified atmosphere packaging and gamma irradiation against *Escherichia coli* O157: H7 and *Salmonella* Typhimurium on green beans. *Food Control.* 50: 215–222 (2015)
- Tamer CE, Çopur OU. Chitosan: an edible coating for fresh-cut fruits and vegetables. *Acta Hort.* 877: 619–624 (2010)
- Tapia M, Rojas-Graü M, Carmona A, Rodríguez F, Soliva-Fortuny R, Martín-Belloso O. Use of alginate-and gellan-based coatings for improving barrier, texture and nutritional properties of fresh-cut papaya. *Food Hydrocoll.* 22: 1493–1503 (2008)
- Treviño-Garza MZ, García S, del Socorro Flores-González M, Arévalo-Niño K. Edible active coatings based on pectin, pullulan, and chitosan increase quality and shelf life of strawberries (*Fragaria ananassa*). *J. Food Sci.* 80: M1823–M1830 (2015)
- Valenzuela C, Tapia C, López L, Bunger A, Escalona V, Abugoch L. Effect of edible quinoa protein-chitosan based films on refrigerated strawberry (*Fragaria × ananassa*) quality. *Electron. J. Biotechnol.* 18: 406–411 (2015)
- Vu KD, Hollingsworth RG, Leroux E, Salmieri S, Lacroix M. Development of edible bioactive coating based on modified chitosan for increasing the shelf life of strawberries. *Food Res. Int.* 44: 198–203 (2011)
- Wang Z, Zheng L, Li C, Zhang D, Xiao Y, Guan G, Zhu W. Modification of chitosan with monomethyl fumaric acid in an ionic liquid solution. *Carbohydr. Polym.* 117: 973–979 (2015)
- Xia W, Liu P, Zhang J, Chen J. Biological activities of chitosan and chitoooligosaccharides. *Food Hydrocoll.* 25: 170–179 (2011)
- Zhang D, Quantick PC. Effects of chitosan coating on enzymatic browning and decay during postharvest storage of litchi (*Litchi chinensis* Sonn.) fruit. *Postharvest Biol. Technol.* 12: 195–202 (1997)
- Zhang C, Ping Q, Zhang H, Shen J. Synthesis and characterization of water-soluble O-succinyl-chitosan. *Eur. Polym. J.* 39: 1629–1634 (2003)

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