Review

Chitosan as a Novel Edible Coating for Fresh Fruits

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Received August 27, 2012; Accepted December 19, 2012

The main benefits of edible active coatings are to maintain the quality and extend shelf-life of fresh fruits and prevent microbial spoilage. Chitosan have a wide range of potential application in different fields of chemical sciences, biological systems, food sciences, pharmaceutical and medical industries. Chitosan has been proven one of the best edible and biologically safe preservative coatings for different types of foods because of its film-forming properties, antimicrobial actions, lack of toxicity, biodegradability and biochemical properties. It has been proven that the chitosan can control numerous pre and postharvest disease of fresh fruits. Chitosan edible coatings extend the shelf life of the fruits and vegetables by minimizing the rate of respiration and reducing the water loss. Chitosan coating offers a defensive barrier against bacterial contamination and loss of moisture from the surface of food products, thus extending their shelf life. With limited increase in the concentration of chitosan coating, the beneficial effect of chitosan on postharvest life and quality of the food is enhanced. The present review delineates the preparation, properties and potential application of chitosan coatings for enhancing the postharvest life and quality of different types of fruits.

Keywords: chitosan, edible coating, fruits, postharvest life, shelf life

Introduction

Consumers usually judge the quality of fresh fruits on the basis of appearance and freshness at the time of purchase (Kader, 2002). However, minimal processing operations alter the integrity of fruits bringing about negative effects on product quality such as browning, off-flavour development and texture breakdown. In addition, the presence of microorganisms on the fruit surface may compromise the safety of fresh-cut fruit. The search for methods that aim to retard these negative effects is of great interest to all the stakeholders involved in the production and distribution of fresh fruits. Traditionally, edible coatings have been used in the fresh fruit industry as a strategy to reduce the deleterious effects that minimal processing imposes on intact vegetable tissues. Edible coatings may contribute to extend the shelf-life of fresh-cut fruits by reducing moisture and solute migration, gas exchange, respiration and oxidative reaction rates, as well as by reducing or even suppressing physiological disorders (Baldwin \textit{et al.}, 1996; Park, 1999). Edible coatings have a high potential to carry active ingredients such as antibrowning agents, colorants, flavours, nutrients, spices and antimicrobial compounds that can extend product shelf life and reduce the risk of pathogen growth on food surfaces (Pranoto \textit{et al.}, 2005). However, specific studies on fresh fruits are rather limited and their industrial implementation is still incipient. In this sense, the main goal of this article is to review and update the information available on the use of edible coatings as carriers of food ingredients (antimicrobials, texture enhancers and nutraceuticals) to improve the safety, quality and functionality of fresh fruits. Much research is still to be done in order to develop safe fresh fruits products with high sensory quality and nutritional value. The development of new processing techniques for preserving freshcut fruit needs to overcome some of the hurdles to successful commercial distribution of such products. Interest in the possible

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use of natural compounds to prevent microbial growth has notably increased in response to consumer awareness of the use of chemically synthesized additives in foods.

Browning is also a major concern related to the extension of shelf-life of fresh fruits, and strongly affects the consumer’s purchase decision. Traditionally, sulfites have been used for browning prevention. However, their use on fresh fruits and vegetables was banned in 1986 by the FDA owing to their potential hazards to health (Buta et al., 1999). Thus, various alternative approaches have been studied to minimize visual deterioration in fresh fruits. Reducing agents such as citric acid, ascorbic acid, isoascorbic acid and sodium erythorbate (Buta et al., 1999; Sapers and Miller 1998; Dong, 2000; Soliva-Fortuny et al., 2002) thiolcontaining amino acids such as N-acetylcysteine and glutathione (Oms-Oliu et al., 2006; Rojas-Gráu et al., 2006), oxalic acid (Son, 2001) and 4-hexylresorcinol (Luo and Barbosa-Cánovas 1997) have been investigated to prevent browning. Calcium treatments can maintain or improve tissue firmness and crispness of fresh fruits. To improve quality of fresh-cut fruit surface treatments such as dipping fruit pieces into aqueous solutions containing antimicrobial agents, antioxidants, calcium salts or functional ingredients such as minerals and vitamins are widely practiced. However, the effectiveness of these compounds could be very much improved with their incorporation into edible coatings at a low concentration to prevent detrimental effect of long exposure to food components. The application of edible coatings to deliver active substances is one of the recent major advances made in order to increase the shelf-life of fresh fruits production.

Chitin and chitosan are biopolymers having immense structural possibilities for chemical and mechanical modifications to generate novel properties, functions and applications. Chitosan refers to the whole family of acidic soluble linear heteropolysaccharides. Chitosan is a natural nontoxic biopolymer derived by deacetylation of chitin, a major component of the shells of crustaceans such as crab, shrimp, and crawfish, it also occurs naturally in some fungi but its occurrence is much less widespread than that of chitin. A sharp nomenclature border has not been defined between chitin and chitosan (Muzzarelli, 1973; Peniche et al., 2003). Chitosan is of great interest because of their all-round properties and applications in almost every field with great potential in diverse industries (Figure 1) (Aranaz et al., 2009, Rinaudo, 2006, Wani et al. 2010). Among these diverse applications, chitosan has a great role in food industry and agriculture (Chien et al., 2007a; No et al., 2007). Much attention has been paid currently to chitosan as a potential polysaccharide resource (Nishimura et al., 1991). Several efforts have been carried out to prepare functional derivatives of chitosan by chemical modifications (Toffey et al., 1996; Kim et al., 1994; Crini et al., 1997) only a few examples attained solubility in general organic solvents (Kurita, 2001; Kurita et al., 1982).

According to the chemical structure of chitosan, it is composed of 2-amino-2-deoxy-D-glucose (glucosamine) monomers, which are linked β-1-4-glycosidically (Figure 2(a)), whereas chitin is composed of N-acetyl-glucosamine monomers (Figure 2(b)) (Rabea et al., 2003). Chitin is insoluble in most organic solvents while as chitosan is readily soluble in dilute acidic solutions below pH 6.0. The presence of the amino groups indicates that pH substantially alters the charged state and properties of chitosan (Yi et al., 2005). As the pH increases above 6, amines of chitosan become deprotonated and the polymer loses its charge and becomes insoluble. The soluble-insoluble transition occurs at its pKa value around pH between 6 and 6.5. As the pKa value is highly dependent on the degree of N-deacetylation, the solubility of chitosan is dependent on the degree of deacetylation and the method of deacetylation used (Cho et al., 2000). The degree of ionization depends on the pH and the pK of the acid with respect to studies based on the role of the protonation of chitosan in the presence of acetic acid and hydrochloric acid.

Fig. 1. Chitosan utilization in various fields of application.

Fig. 2. Chemical structure of 100% acetylated chitin (a) and chitosan (b).
(Rinaudo et al., 1999a; Rinaudo et al., 1999b). However, no comprehensive review has yet been published that covers the entire range of applications of chitosan particularly in fruit preservation.

**Preparation of Chitosan**

**Extraction and Purification of Chitin**

Chitin is present within numerous taxonomic groups. However, commercial chitins are usually isolated from marine crustaceans, mainly because a large amount of waste is available as a by-product of their food processing. It occurs in the skeletal material of crustaceans such as crabs, lobsters, shrimps, prawns and cray fish (Figure 3).

While much research has been done with chitosan extraction from crab shell, limited information is available on the extraction possibilities with crawfish shell waste. Crustacean shells consist of 30−40% proteins, 30−50% calcium carbonate and 20−30% chitin and contain pigments of a lipidic nature such as carotenoids (astaxanthin, astathin, canthaxanthin, lutein and β-carotene). These proportions vary with species and with season. Chitin is extracted by acid treatment to dissolve the calcium carbonate followed by alkaline extraction to dissolve the proteins and by a depigmentation step to obtain a colourless product mainly by removing the astaxanthine (Acosta et al., 1993). The materials which are used for the preparation of chitosan are the exoskeletons of various crustacea particularly crab and shrimp. The Chitin extraction is closely associated with proteins, inorganic material like CaCO₃, pigments of a lipidic nature. Different well known procedures have been implemented to remove these impurities.

Demineralization, deproteinization, decolorization, and deacetylation are the four traditional steps for the isolation of chitin (Figure 4). Demineralization and deproteinization are the two specific steps for the isolation of chitin, which involves the dissolution of calcium carbonate with 1.0 N HCl and the removal of proteins with 3% NaOH, respectively. The demineralization process is mostly carried out by treatment with HCl and deproteinization by treatment with NaOH. In most of the cases, deproteinization has been carried out prior to demineralization. Various researchers have examined and used enzymes for protein removal. The use of enzymes such as pepsin and trypsin has been suggested, if the chitin is required to be as fully N-acetylated as possible, but no experimental details were given.

**Deacetylation of Chitin**

The physicochemical characteristics of chitosan are the degree of deacetylation and its molecular weight. These parameters play a key role for the quality of chitosan in its...
carried out by acid hydrolysis using HCl or by oxidative reaction using HNO₂ and H₂O₂ (Prashanth and Tharanathan, 2007). It has been found to be specific in the sense that HNO₂ attacks the amino group of D-units, with subsequent cleavage of the adjacent glycosidic linkage. In enzymatic depolymerization, several enzymes such as chitinase, chitosanase, gluconase and some proteases have produced low molecular weight chitosan with high water solubility. Non-specific enzymes including lysozyme, cellulase, lipase, amylase and pectinase that are capable of depolymerizing chitosan are known (Muzzarelli, 1977). In this fashion, regioselective depolymerization under mild conditions is allowed. However, the expensive cost of enzymes inhibits their use in a commercial application. Physical depolymerization can be carried out by ultrasonication and irradiation but the product varies applications (Kumar, 2000; Kumar et al., 2004; Tharanathan and Kittur, 2003; Pradip et al., 2002). The major difference between chitin and chitosan lies in their solubility. The degree of deacetylation is the proportion of glucosamine monomer residues in chitin. Deacetylation has a striking effect on the solubility and solution properties of chitin. The degree of deacetylation could influence the performance of chitosan in many of its applications. It determines the content of free amino groups in the polysaccharides and can be employed to differentiate between chitin and chitosan. The process of deacetylation involves the removal of acetyl groups from the molecular chain of chitin, leaving behind a complete amino group (-NH₂) and chitosan versatility depends mainly on this high degree chemical reactive amino groups. One of the main reactions carried out on chitin is deacetylation, mostly by using aqueous alkali. The most frequently used alkali is NaOH. The level of deacetylation is governed by the alkali concentration, time of reaction, temperature, particle size and density. While treatment with 50 wt% NaOH at 100°C for 1 hour gives a product having 82% deacetylation (Figure 5), extending the reaction time to 48 h enables almost 100% deacetylation but at the expense of a considerable decrease in solution viscosity indicating chain degradation (Muzzarelli et al., 1980). Because of this the degree of deacetylation is an important property in chitosan production as it affects the physicochemical such as properties and different potential applications. Deacetylation also affects the biodegradability and immunological activity (Tolaimate et al., 2000). This deacetylation determines its appropriate applications in different fields of research.

**Depolymerization of Chitosan**

Chitosan and its derivatives have a wide range of applications, for example thickening, film formation, metal binding and antimicrobial activity. These applications of chitosan have been found to be dependent on their molecular weight and degree of deacetylation (No et al., 1997). Additionally, controlling depolymerization of this material is useful in order to adjust properties like viscosity, solubility and biological activity (Rege and Block, 1999). The native chitosans have quite large molecular weight, therefore, it is necessary to establish a reproducible method for generating low molecular weight chitosan. In general, low molecular weight chitosan can be prepared from high molecular weight chitosan by the depolymerization process. Chitosan depolymerization can be carried out chemically, enzymatically or physically. In chemical depolymerization, various acids such as hydrochloric acid, nitrous acid, phosphoric acid and hydrogen fluoride have been used to obtain low molecular weight chitosan. Chemical depolymerization as shown in Figure 6 is mostly carried out by acid hydrolysis using HCl or by oxidative reaction using HNO₂ and H₂O₂ (Prashanth and Tharanathan, 2007). It has been found to be specific in the sense that HNO₂ attacks the amino group of D-units, with subsequent cleavage of the adjacent glycosidic linkage. In enzymatic depolymerization, several enzymes such as chitinase, chitosanase, gluconase and some proteases have produced low molecular weight chitosan with high water solubility. Non-specific enzymes including lysozyme, cellulase, lipase, amylase and pectinase that are capable of depolymerizing chitosan are known (Muzzarelli, 1977). In this fashion, regioselective depolymerization under mild conditions is allowed. However, the expensive cost of enzymes inhibits their use in a commercial application. Physical depolymerization can be carried out by ultrasonication and irradiation but the product
yield has been observed to be low (Choi et al., 2002; Baxter et al., 2005). The most important thing about the limitations in the use of chitosan in a number of applications is its high viscosity and low solubility at neutral pH.

**Chitosan Based Coatings**

Chitosan is a polycationic polymer with specific structure and properties and contains more than 5000 glucosamine units and is the second most abundant natural polymer after cellulose. Similar to the cellulose, chitosan is a fiber, but different from plant fiber, chitosan possesses unique properties including the ability to form films. Because of positive ionic charge on chitosan, it has the ability to bind chemically with negatively charged fats, lipids and bile acids (Sandford, 1992). Chitosan has been wide range in applications in various fields, like waste management, food processing, nanotechnology, medicine and biotechnology. Chitosan is very interesting material in pharmaceutical applications due to its low toxicity, biodegradability and biocompatibility. Chitosan, as a natural polycation compound with antifungal activity (Bautista-Banos et al., 2006; Liu et al., 2007) capability for induction of the host resistance to pathogens (Trotel-Aziz et al., 2006) and ability to create a semi-permeable film on fruit surface (Bautista-Banos et al., 2006; Jiang et al., 2005) has been proven to be a natural potential fungicide in postharvest fruit. It has been reported that postharvest application of chitosan coating has a good control effect on decay of grapes (Meng et al., 2008; Romanazzi et al., 2002). It is also revealed that preharvest spray of antagonist combined with postharvest chitosan coating could more significantly enhance control effect on decay of grapes in storage than preharvest treatment alone. It is well known that fruit quality is also a crucial factor in evaluating the effect of storage. Preharvest-treated fruit maintained a higher ratio of soluble solids content/titratable acid by increasing SSC and decreasing TA as compared to control fruit both in low temperature storage and at 20°C. Chitosan coating form a selective permeable film on fruit surface, which result in limiting respiration and transpiration (Bautista-Banos et al., 2006). It is beneficial at reducing weight loss of grapes in storage. At shelf time, high weight loss in preharvest spray of antagonist + postharvest chitosan coating treated fruit may be due to the reason that high temperature resulted in an increase of respiration metabolism of fruits and the loss of water absorbed by the chitosan film on the fruit surface (Meng et al., 2008; Wiles et al., 2000). Therefore, addition of some edible lipid to film forming solution should be further investigated use of chitosan, in order to prevent water loss and to maintain quality of table grapes. The capacity of chitosan coating to inhibit the growth of several fungi has been shown for a wide variety of harvested commodities. According to the work carried out by El Ghaouth et al. (1992) on two postharvest pathogens, Botrytis cinerea and Rhizopus stolonifer, the antimicrobial activity of chitosan on strawberries appears to be related to the ability of this biopolymer to cause severe cellular damage to the mold and interfere in the secretion of polygalacturonases rather than its ability to induce plant defence enzymes. The concentration of chitosan in the coating solution affects the fungal decay of the fruit. A concentration of 1.5% inhibits fungal growth during the storage period whereas fungal decay was observed in fruit coated with a 1% chitosan solution. It can be expected that an increase in the viscosity of the chitosan coating solution will increase the content of chitosan adhered to the fruit surface and the uniformity of the coating. Studies carried out by Cisneros-Zevallos and Krochta (2003), on Fuji apples coated with hydroxypropyl methylcellulose, showed that the dry coating load on the fruit surface is a function of the viscosity, draining time and solid concentration of the coating solution. The effect of the coating solution concentration on the dry matter adhered to the fruit surface has been observed to be more pronounced for high viscosity hydrocolloids. The above mentioned study has been carried out with high molecular weight chitosan, which could explain the differences observed in the extent of fungal decay between fruits dipped in 1% and 1.5% chitosan. The combined treatment of 1% chitosan solution and 0.5% calcium gluconate inhibited the fungal decay of fruit during the storage period. The incorporation of calcium ions in fruit tissue promotes new cross-links between anionic homogalacturonans, strengthening the cell wall and particularly the middle lamella, which is responsible for holding cells together. Thus, increasing the stability of the cell wall and middle lamella by calcium treatment can be expected to improve strawberry resistance to enzymes caused by fungal pathogens, while as the chitosan coating reduces respiration activity, thus delaying ripening and the progress of fruit decay due to senescence and The addition of calcium gluconate to the chitosan coating formulation increased the nutritional value by incrementing the calcium content of the fruit (Hernández-Muñoz et al., 2008).

**Edible Coatings**

The use of edible coatings signifies one of the significant methods for preserving quality. Edible coatings have been traditionally used to improve food appearance and maintain quality because they are considered eco-friendly (Khwaldia et al., 2004). Coating films can act as barriers to moisture and oxygen during processing, handling and storage (Xu et al., 2007). Moreover, they can retard food deterioration by inhibiting the growth of microorganisms, due to their natu-
ral intrinsic activity or to the incorporation of antimicrobial compounds (Cha and Chinnan, 2004). Normally, edible films are made of proteins or polysaccharides that can also help to maintain moisture, thereby improving shelf life. Dips of antimicrobial solutions are commonly practiced to improve microbial stability of fresh-cut fruit. However, these antimicrobial agents rapidly disperse into the food, therefore, reducing efficacy due to a decrease in concentration on the fruit surface. The incorporation of antimicrobial agents into edible coatings provides more inhibitory effects against spoilage and pathogenic bacteria by maintaining effective concentrations of the active compounds on the food surfaces (Gennadios and Kurth, 1997). The use of edible coatings in combination with antimicrobial properties or with amalgamation of antimicrobial compounds is a potential alternative to enhance the safety and quality of fresh fruits. Chitosan coatings containing bergamot oil produced the most effective antimicrobial activity, and showed the greatest inhibition of the respiration rates in terms of both O2 consumption and CO2 generation (Sánchez-González et al., 2011). Several types of edible coatings have been used for extending shelf-life of fresh commodities. Chitosan is one of the best examples of edible coatings for improving the quality and resistivity of the fresh cut fruits (Romanazzi et al., 2002; Chien et al., 2007). The effectiveness of chitosan in maintaining quality and extending shelf-life of sliced mango has been reported by Chien and his coworkers (Chien et al., 2007). Assis and Han also proposed chitosan for extending the shelf-life of sliced apples and fresh strawberries, respectively (Assis et al., 2004; Han et al., 2005). Chitosan-based edible film has been used on strawberries to increase the shelf-life (Park et al., 2005). A reduction in the counts of aerobic and coliforms microorganisms was also observed during storage.

Effect of Chitosan Coating Treatments on the Physical Characteristics of Fruits

Sensory Evaluation and Sensory Quality

Papaya (Carica papaya L.) is one of the most important fruit crops grown in the tropical and sub-tropical regions of the world. Being a climacteric fruit, papaya has a short postharvest life, thus, research has focused on minimising postharvest losses in order to prolong shelf life. Chitosan has been proved one of the best preservative material that delay the ripening process by inhibiting the respiration rate in the Eksotika II papaya fruit during cold storage (Ali et al., 2005). On Chitosan treatment an effective control in weight loss reduction, maintained firmness, delayed changes in the peel colour and soluble solids concentration have been observed during 5 weeks of storage. The titratable acidity declined throughout the storage period, though at a slower rate in the chitosan coated fruit as compared to the control. The rate of respiration reduces in the chitosan treated fruits may be the reason of delayed senescence and a reduced susceptibility to decay (Romanazzi et al., 2005). Ali and his coworkers results have revealed significant differences in taste, peel and pulp colour, texture, and flavour. A bench of judges gives their remarks on the sensory evaluation of all fruits for taste, peel colour, pulp colour, texture and flavour. The fruits treated with 1.5% chitosan attained maximum score by the panelists in all tested parameters. The untreated fruits or those treated with 0.5% chitosan ripened after 3 weeks of storage and, thereafter began to decompose. These fruits were therefore not presented to the panelists for sensory evaluation. The fruits treated with 2.0% chitosan were unable to ripen properly even after 5 weeks of cold storage, and were discarded from the evaluation due to unacceptable quality. The ripe fruits with 1.5% chitosan coating had a gloss and no wrinkles, therefore scoring 3.84, for peel colour, which was significantly higher than the other treated fruit. The fruits with 1.0% chitosan coating also had a good overall appearance but with some wrinkles. The most attractive pulp with the characteristic reddish orange colour of Eksotika II papaya was found in the fruits with 1.5% chitosan (4.30), followed by 1.0% coated fruits (3.80), which were significantly inferior in the pulp colour. There were significant differences in the texture of the fruits with the different coating treatments. The fruits with 1.5% coating were rated the highest (3.98 points), with a firm, crisp pulp, which ‘melted’ in the mouth. The flavour of the fruits with 1.5% chitosan coating was rated excellent (4.24), because the pulp was not only sweet and pleasant, but also possessed a characteristic aroma. The sensory attributes of the papaya fruits treated with 1.5% chitosan concentration demonstrated the overall superiority, after 5 weeks of cold storage. Kittur et al. (2001) observed that 1.0% chitosan coated mangoes had better sensory traits than the control and the waxol treated mangoes, after 21 days of storage.

Litchi (Litchi chinensis Sonn.) is a tropical fruit with high commercial value in the international market. However, once detached from the tree, the fruit loses its qualities, such as sweet and juicy flesh and attractive bright red pericarp, within a couple of days under ambient temperatures. The short shelf life of litchi greatly limits the marketing of the fruit and has created many restrictions in the litchi industry. It has been observed that both taste and colour scales of litchi pulp decreases rapidly during storage. The pulp taste scale and/or colour scale can reflect litchi fruit quality, and moreover, the decrease in the taste scale was associated well with the reduction in the colour scale (Jiang et al., 2003). Chitosan coating delayed the decline in sensory quality, and extended
shelf life. Both of the control and the chitosan-coated peeled fruit were commercially acceptable after 3 days of storage. However, after 6 days of storage, the control became market-
ably unacceptable while the chitosan-coated peeled fruit still had good quality. There was not any significant difference in the sensory quality among treatments with 1%, 2% and 3% chitosan after 3 days but significant difference between treat-
ments with 1% and 2% chitosan after 6 days of storage (Dong et al., 2004). Pen and Jiang (2003) reported that chitosan coating improved the quality attributes and extended shelf life of fresh-cut Chinese water chestnut by reducing respira-
tion and inhibiting activities of polyphenol oxidase and per-
oxidase. In this study, the beneficial effects of chitosan coat-
ing on the fruits should be mainly attributed to the protective effects preventing from surface browning and cracking, and juice leaking.

Weight Loss

Fruit weight loss is mainly associated with respiration and moisture evaporation through the skin. The thin skin of strawberry fruits makes them susceptible to rapid water loss, resulting in shrivelling and deterioration. The rate at which water is lost depends on the water pressure gradient between the fruit tissue and the surrounding atmosphere, and the stor-
age temperature. Low vapour pressure differences between the fruit and its surroundings and low temperature are recom-
manded for the storage of strawberries. Dehydration will also cause increase in surface-wounded fruit. Edible coatings act as barriers, thereby restricting water transfer and protecting fruit skin from mechanical injuries, as well as sealing small wounds and thus delaying dehydration. Weight loss during storage (10°C and 70 ± 5% RH) of uncoated fruit compared to fruit coated with 1% and 1.5% chitosan, with and without the addition of CaGl. All samples demonstrated a gradual loss of weight during storage. Throughout storage, the weight loss of uncoated fruit was significantly greater than that of coated fruit. At the end of storage, untreated strawber-
rries showed 28.7% loss in weight, whereas the weight losses of samples coated with 1% and 1.5% chitosan were 19.6% and 14.2%, respectively. The greater viscosity of the 1.5% chitosan solution likely results in a coating of greater thickness, further reducing moisture loss. Incorporation of CaGl into the film-forming solution did not have any significant effect on weight loss reduction of strawberries. Similarly, in case of grapes, (Sánchez-González et al., 2011) Weight loss occurred mainly during the first 3 days of storage and was more pronounced for the control samples and those coated with a pure chitosan coating than for the samples with coat-
ings containing bergamot oil which showed the smallest weight losses. The effect of storage time led to no signifi-
cant, observable differences. Therefore, with the exception of the pure chitosan coating, the rest provided a significant water vapour barrier, showing lower weight losses than the uncoated samples. In both matrices, the addition of bergamot oil improved this property, as may be expected from its hy-
drophobic nature. These results are coherent with the values of the water vapour permeability (WVP) of the isolated films reported in previous studies, where chitosan films exhibited greater WVP than HPMC films (Vargas et al., 2008) and, in both cases, a significant reduction of this property was obtained when an essential oil was incorporated (Sánchez-
González et al., 2009, 2010a, 2010b). Apart from strawberry and grape fruits, chitosan coatings have been effective at controlling water loss from other commodities, including cucumber and pepper (El Ghaouth et al., 1991), papaya (Ali et al., 2011) and longan fruit (Jiang and Li, 2001). The addi-
tion of lipids and surfactants improves the moisture retention of the coating, although it also causes undesirable effects on the sensory quality of fruit. Chitosan has been reported to be more effective at delaying weight loss in banana and mango (Kittur et al., 2001) and strawberries (Ribeiro et al., 2007) than are starch and cellulose derivatives. The weight loss appeared to be the major determinant of storage life and quality of fruits. Chitosan coatings significantly reduced the weight loss of the fruits during storage compared to the control. The minimum weight loss was observed in the chitosan treatments of 1.5% and 2.0%. The slower rate of moisture loss from the chitosan coated fruits may be attributed to the additional barrier against diffusion through stomata (Paull and Chen, 1989). In the papaya fruit, it is believed that the major pathway for water loss is through the peel (Seymour et al., 1993). The decline in the cuticle integrity as ripening progresses is thought to be due to latex disruption (Perez-
Gago et al., 2006). Paull and Chen (1989) found six times the weight loss in solo papaya in which the cuticle was dis-
rupted with solvents. It is evident from this study that coating papaya with chitosan reduced the weight loss compared with the control fruit, probably as a result of covering the cuticles on the fruit surfaces. According to Perez-Gago et al. (2006) water loss can be reduced by covering with a plastic film or coating. In this study, the chitosan applied, formed a film on the fruit skin, reducing the water and weight loss. The application of 1.5% and 2.0% chitosan coatings reduced the weight loss to < 6% of that of the control, which is sufficient to maintain a good appearance and the quality of Eksotika II papaya.

Application of chitosan coating retarded the weight loss of peeled litchi fruit. After 6 days of storage, there were 9% (the highest) and 6% (the lowest) of weight loss of the control and 2% chitosan-coated peeled fruit, respectively. The
The bright red color of strawberry fruit is due to the presence of anthocyanins and other phenolics to quinones. The quinones subsequently undergo polymerization, producing characteristic yellow to brown colors in the fruit tissue (Mayer and Harel, 1979; Spanos and Wrolstad, 1992). Changes in anthocyanins seem to be one of the causes of fruit browning, and their degradation is the result of coupled oxidation by PPO in the presence of other phenolic compounds (Kader et al., 1999; Jiang, 2000; Zhang et al., 2000). Nunes and his coworkers (2005) have observed that water loss is one of the major factors that contribute to changes in color of stored strawberries. Water loss plays an important role in anthocyanin degradation. Pigment degradation is caused by increased PPO activity as a result of physiological stress due to water loss might contribute to the development of strawberry surface browning during storage. Water loss accelerates senescence of the fruit, leading to membrane degradation and release of PPO and ascorbate oxidase substrates from the vacuole, leading in this way to oxidation of the cellular components. Caro and Joas (2005) revealed that the rapid postharvest browning of litchi fruit pericarp is the result of polyphenol oxidase activity, anthocyanin hydrolysis, and nonenzymatic polymerization of o-quinones into melanins. Many researchers form the chitosan coatings by dipping fruits in chitosan solution and studied the effect of chitosan coating on browning of litchi fruit (Zhang and Quantick, 1997; Caro and Joas, 2005; Jiang et al., 2005; Joas et al., 2005; Jiang et al., 2003). Zhang and Quantick (1997) reported that chitosan coating, irrespective of concentration (1% and 2% dissolved in 2% glutamic acid), delayed changes in contents of anthocyanins, flavonoids, and total phenolics. It also delayed the increase in polyphenol oxidase (PPO) activity and partially inhibited the increase in peroxidase activity. Jiang et al. (2005) also similarly observed that chitosan (2% in 5% acetic acid) coating delayed the decrease in anthocyanin content and the increase in PPO activity. Such effects of chitosan coating were also observed with peeled litchi fruit (Dong et al., 2004), longan fruit (Jiang and Li, 2001), and fresh-cut Chinese water chestnut vegetable (Pen and Jiang, 2003). Both polyphenol oxidase and peroxidase activities activities of peeled litchi fruit increased during storage. The peeled fruit coated with chitosan had reduced activities of polyphenol oxidase and peroxidase after six days of storage and exhibited that the coating inhibited the two enzymes. However, the inhibition effect of activities of polyphenol oxidase and peroxidase of the fruit stored for six days at −1°C was not enhanced significantly when the concentration of chitosan coating increased from 2 % to 3 %.

**Polyphenol Oxidase and Peroxidase Activities**

Colour is one of the most important factors in fresh fruit appearance and greatly contributes to fruit quality. Discolouration of fruits is undesirable because it results in the fruit losing fresh color and glossiness. In fact, browning in fruits is primarily attributed to PPO activity, which is able to act on phenolic compounds in the presence of oxygen (Nicolas et al., 1994). Colour changes in harvested, fully red, ripe strawberries occur progressively during storage. The bright red color of strawberry fruit is due to the presence of anthocyanin pigments in the fruit epidermis and cortex. Strawberry pigments, like other anthocyanins, are relatively unstable and may easily lose their bright color due to degradation by oxidative enzymes such as polyphenol oxidase (PPO), which is primarily localized in the cortex of strawberry fruit with the anthocyanins and other phenolics (López-Serrano and Ros Barceló, 2001). PPO catalyzes the hydroxylation of monophenolics, leading to the formation of o-diphenol compounds and to the oxidation of o-dihydroxy compounds to quinones. The quinones subsequently undergo polymerization, producing characteristic yellow to brown colors in the fruit tissue (Mayer and Harel, 1979; Spanos and Wrolstad, 1992). Changes in anthocyanins seem to be one of the causes of fruit browning, and their degradation is the result of coupled oxidation by PPO in the presence of other phenolic compounds (Kader et al., 1999; Jiang, 2000; Zhang et al., 2000). Nunes and his coworkers (2005) have observed that water loss is one of the major factors that contribute to changes in color of stored strawberries. Water loss plays an important role in anthocyanin degradation. Pigment degradation is caused by increased PPO activity as a result of physiological stress due to water loss might contribute to the development of strawberry surface browning during storage. Water loss accelerates senescence of the fruit, leading to membrane degradation and release of PPO and ascorbate oxidase substrates from the vacuole, leading in this way to oxidation of the cellular components. Caro and Joas (2005) revealed that the rapid postharvest browning of litchi fruit pericarp is the result of polyphenol oxidase activity, anthocyanin hydrolysis, and nonenzymatic polymerization of o-quinones into melanins. Many researchers form the chitosan coatings by dipping fruits in chitosan solution and studied the effect of chitosan coating on browning of litchi fruit (Zhang and Quantick, 1997; Caro and Joas, 2005; Jiang et al., 2005; Joas et al., 2005; Jiang et al., 2003). Zhang and Quantick (1997) reported that chitosan coating, irrespective of concentration (1% and 2% dissolved in 2% glutamic acid), delayed changes in contents of anthocyanins, flavonoids, and total phenolics. It also delayed the increase in polyphenol oxidase (PPO) activity and partially inhibited the increase in peroxidase activity. Jiang et al. (2005) also similarly observed that chitosan (2% in 5% acetic acid) coating delayed the decrease in anthocyanin content and the increase in PPO activity. Such effects of chitosan coating were also observed with peeled litchi fruit (Dong et al., 2004), longan fruit (Jiang and Li, 2001), and fresh-cut Chinese water chestnut vegetable (Pen and Jiang, 2003). Both polyphenol oxidase and peroxidase activities activities of peeled litchi fruit increased during storage. The peeled fruit coated with chitosan had reduced activities of polyphenol oxidase and peroxidase after six days of storage and exhibited that the coating inhibited the two enzymes. However, the inhibition effect of activities of polyphenol oxidase and peroxidase of the fruit stored for six days at −1°C was not enhanced significantly when the concentration of chitosan coating increased from 2 % to 3 %.

**Total Soluble Solid, Titrable Acidity and Ascorbic Acid**

Fruits are essential for the proper maintenance of human health. Fruits are foods rich in vitamins and minerals and...
supply arrays of colours, flavour, texture and bulkiness to the pleasure of eating. Total soluble solid, titratable acidity and ascorbic acid contents of peeled litchi fruit decreased markedly after 6 days of storage, compared to the peeled fruit before storage (Dong et al., 2004). The peeled fruit treated with chitosan had higher contents of total soluble solid, titratable acidity and ascorbic acid, but there was no significant difference in total soluble solid among three treatments with 1%, 2% and 3% chitosan. Guava (Psidium guajava L.) is an important subtropical fruit grown widely in tropical and subtropical regions of the world. Previous studies have indicated that fresh-cut guava coated with chitosan delayed weight loss and increase of soluble solids content, while it did not have any significant effect on firmness and titratable acidity reduction compared to the control (Thommohaway et al., 2007). Hong et al. (2012) reported the potential effects of chitosan coating and effects of different concentration of chitosan coatings on physiochemical characteristics of guava fruit during the cold storage. Hong and his co-workers investigated that the soluble solids content of control and 0.5% chitosan coating fruit samples increased drastically however samples coated with 1.0 and 2.0% showed a slight increase during 12 days storage. On day 6 of storage a significant difference was observed between chitosan coated samples and the uncoated samples and fruit coated with 0.5 and 2.0% chitosan showed significant effect on soluble solids content on day 9. Throughout the storage period, the lowest level of soluble solids content has been observed in guava coated with 2.0% chitosan. Fruits treated with 1.0 and 2.0% chitosan did not show significant difference in soluble solids content. The effect of chitosan coating on soluble solids content of guava fruit was probably due to the slowing down of respiration and metabolic activity, hence retarding the ripening process. Due to the filmogenic property of chitosan a semipermeable film is formed around the vegetable and fruit therefore, effectively delaying fruit ripening. The chitosan coating at 2.0% was probably able to modify the internal atmosphere of the fruit to prevent the decrease in titratable acidity contents. Therefore, the 2.0% chitosan coating produced a small change in titratable acidity throughout storage. Han et al. (2004) also observed lower acidity loss during storage in strawberry, peach, tomato and litchi coated with chitosan.

**Loss of Fruit Due to Visible Fungal Growth**

Research to reduce fungicide applications in agriculture through the discovery of new natural antimicrobials is needed to meet the growing consumer demand for food without chemical preservatives and to respond to the needs of sustainable farming. Due to the nontoxic and biocompatible properties of chitosan (Wu et al., 2005), it has been considered a candidate for substitution of fungicides in horticultural cultivation (Bautista-Banos et al., 2006). The main difference between the practical grade chitosan solutions and the commercial chitosan formulation arises from the techniques of their preparation. Chitosan has a dual effect on host-pathogen interactions through its antifungal activity and its ability to induce plant defense responses (Romanazzi, 2010). Moreover, as chitosan can form an edible film when applied to the surface of fruit and vegetables, it is clearly effective in conferring a physical barrier to moisture loss, delaying dehydration and fruit shriveling. Therefore, its coating can prolong storage life, delay the drop in sensory quality, and control the decay of strawberry fruit (Han et al., 2004; Park et al., 2005; Chaiprasart et al., 2006; Hernandez-Muñoz et al., 2006; Ribeiro et al., 2007). Chitosan coating can be used as a vehicle for incorporating functional ingredients, such as antimicrobials or nutraceutical compounds that could enhance the effects of chitosan coating or reinforce the nutritional value of the strawberries (Vargas et al., 2006; Vu et al., 2011; Perdones et al., 2012). This study compared the effectiveness of practical grade chitosan when used in solution with acetic, glutamic, formic and hydrochloric acids, and a water-soluble commercial chitosan formulation, in controlling postharvest diseases of strawberry. The commercial chitosan formulation and other resistance inducers based on benzothiadiazole, oligosaccharides, soybean lecithin, calcium and organic acids, and Abies sibirica and Urtica dioica extracts were tested. The commercial chitosan formulation was as effective as the practical grade chitosan solutions in the control of gray mold and Rhizopus rot of strawberries immersed in these solutions and kept for 4 days at 20 ± 1°C (Romanazzi et al., 2013).

Uncoated strawberries showed signs of fungal decay after the third day of storage at 10°C. After six days of storage, 33.5% of uncoated fruit was infected by molds while no sign of fungal decay could be detected by visual inspection of
Fruits coated with 1.5% chitosan or 1.5% chitosan + 0.75% CaGlu. Of the fruit coated with 1% chitosan, 12.5% was observed to be infected on the sixth day of storage. The capacity of chitosan coating to inhibit the growth of several fungi has been shown for a wide variety of harvested commodities. According to the work carried out by El Ghrouth et al. (1992) on two postharvest pathogens, Botrytis cinerea and Rhizopus stolonifer, the antimicrobial activity of chitosan on strawberries appears to be related to the ability of this biopolymer to cause severe cellular damage to the mold and interfere in the secretion of polygalacturonases rather than its ability to induce plant defence enzymes. The concentration of chitosan in the coating solution affects the fungal decay of the fruit. Studies carried out by Cisneros-Zevallos and Krochta, on Fuji apples coated with hydroxypropyl methylcellulose, showed that the dry coating load on the fruit surface is a function of the viscosity, draining time and solid concentration of the coating solution. The effect of the coating solution concentration on the dry matter adhered to the fruit surface has been observed to be more pronounced for high viscosity hydrocolloids. The present study was carried out with high molecular weight chitosan, which could explain the differences observed in the extent of fungal decay between fruits dipped in 1% and 1.5% chitosan. The combined treatment of 1% chitosan solution and 0.5% calcium gluconate inhibited the fungal decay of fruit during the storage period. The incorporation of calcium ions in fruit tissue promotes new cross-links between anionic homogalacturonans, strengthening the cell wall and particularly the middle lamella, which is responsible for holding cells together. Thus, increasing the stability of the cell wall and middle lamella by calcium treatment can be expected to improve strawberry resistance to enzymes caused by fungal pathogens. Pure chitosan coatings have previously been reported to have antifungal effect when applied to cold stored strawberries (Vargas et al., 2006). Recently it has been shown that the Chitosan coatings reduced the percentage of infected strawberries as compared to non-coated ones (control) after three storage days. The antifungal effect of bioactive coatings prepared with modified chitosan and limonene or peppermint essential oil on the fungal decay of cold-stored strawberries has recently been evaluated (Vu et al., 2011). The use of pure chitosan film led to a reduction in the growth of B. cinerea, thus showing a certain degree of antifungal activity. This antifungal activity of chitosan films was enhanced by the addition of lemon essential oil (Perdones et al., 2011). Figure 7 clearly demonstrated the uncoated strawberries are dehydrated and are largely contaminated by moulds after storage whereas strawberries coated with edible bioactive coating based on modified chitosan kept a good hydrated, red-colored appearance after storage for many days (Vu et al., 2011). Functionalized chitosan-based edible coating could become a promising method to carry specific antifungal agents without detrimental effects on strawberries or other fruits.

**Firmness**

Texture is a critical quality attribute in the consumer acceptability of fresh fruit and vegetables. Strawberry is a soft fruit that suffers a rapid loss of firmness during ripening which contributes greatly to its short postharvest life and susceptibility to fungal contamination. Fruit texture properties are affected by cell turgidity and the structure and composition of the cell wall polysaccharides. The biochemical basis of strawberry softening is not clear. Strawberry softening has been associated with the degradation of the middle lamella of cortical parenchyma cells, resulting in a dramatic increase in pectin solubilisation, with slight changes in pectin molecular weight and (Koh and Melton, 2002) small decreases in the content of hemicelluloses. Changes in flesh firmness of control and treated fruit during the storage period of six days at 10°C and 70 ± 5% RH, all the samples presented similar initial flesh firmness values. Chitosan coatings exerted a beneficial effect on fruit firmness such that, by the end of the storage period, all the treatments gave rise to fruit with higher flesh firmness values than untreated fruit. Indeed, chitosan treatment retained the initial flesh firmness of fruit and significant differences were only found on the sixth day of storage. By contrast, uncoated fruit lost its firmness gradually during the storage period. Significant differences were noted between 1% and 1.5% chitosan coating treatments, higher.
values for flesh firmness being found for fruit coated with 1.5% chitosan. The beneficial effect of the elevated chitosan concentration on firmness has also been reported for tomato (El Ghaouth et al., 1992), peach, Japanese pear, kiwifruit (Du et al., 1997), ‘Murcott’ tangor (Chien et al., 2007), papaya (Ali et al., 2011) and guava (Keqian Hong et al., 2012). Fruit firmness is a major attribute that dictates the postharvest life and quality of fruit. Chitosan coatings significantly reduced the loss in firmness of fruits during storage. Fruit firmness increased as chitosan concentration increased. The retention of firmness with chitosan coating is in agreement with the results of Bautista-Banos et al. (2003), where solo papayas treated with 1.5% chitosan coating were firmer than the control during 14 days storage, at ambient temperature. Fruits, such as mango, strawberry, tomato and pears, have also been reported to be firmer when coated with chitosan (Zhu et al., 2008). Fruit softening was greatly reduced as the chitosan concentration increased. The control and 0.5% treated fruit lost their textural integrity faster than the higher concentration coatings, which largely maintained the fruit appearance and quality until the end of storage. Fruit softening is due to deterioration in the cell structure, the cell wall composition and the intracellular materials (Seymour et al., 1993). It is a biochemical process involving the hydrolysis of pectin and starch by enzymes, such as wall hydrolases. The initial softening of papaya is characterised by an increased solubility of the cell wall pectin and the softening of pectin (Lazan and Ali, 1993). The maintenance of firmness in the fruits treated with 1.0%, 1.5% and 2.0% chitosan coatings could be due to their higher antifungal activity and covering of the cuticle and lenticels, thereby reducing infection, respiration and other ripening processes during storage (Asgar et al., 2005; Martinez-Romero et al., 2006). A recent study (Kerch et al., 2011) indicated that coatings of chitosan and chitooligosaccharides applied to strawberries led to an improvement in fruit firmness and to a reduction in vitamin C and anthocyanin content.

Respiration Rate

It is known that the environmental temperature affects the fruit respiration and the respiration affects the fruit temperature in return (Luo and Cai, 2001). When the temperature around the fruit rises, the respiration increases which leads to the increase of the temperature inside the fruit. The effect of storage temperature on the respiration rate of litchi coated with chitosan solution is well discussed in the literature (Lin et al., 2011). The respiration rate of litchi with chitosan coating was lower than the uncoated litchi. The pericarp’s temperature was lower than the ambient temperature because of litchi’s transpiration. It meant that litchi coated with chitosan had produced less bio-heat than that of uncoated. Chitosan coating had definite moisture absorption and retention abilities as found above. Furthermore, chitosan coating on litchi pericarp had two sides: the outside surface had characteristics of air-dried film that chitosan molecular chains had arranged in order and closely packed like a barrier to prevent the passage of heat from surrounding into litchi. Uncoated pericarp had no protective barrier thus facilitating heat transfer from surrounding into litchi, which led to water loss. As a result, chitosan film could restrain the respiration of litchi and produce less the bio-heat in storage period. Table 1 shows the change of respiration rate with the increasing of storage time (Lin et al., 2011).

The difference in respiration rate of the treatment was lower than that of the control during the storage period. After the storage for 6 days, the difference in respiration rate of the treatment was found to be 0.32 (Lin et al., 2011). The respiration rate was increased up to 10.95 for control. The change of respiration rate of the treatment was lower, i.e. the respiration of litchi coated with chitosan was maintained at a low state. It implied that the saccharine of the treatment for respiration was exhausted little and it led to extension of litchi’s shelf life. In addition, the effect of chitosan coatings on the CO₂ production of strawberries stored at 10°C for six days. On the first day of storage, chitosan coating had a stimulatory effect on the respiration rate, a phenomenon that has been reported previously for strawberries (El Ghaoth, 1991; Perdones et al., 2012) and tomatoes (El Ghaoth et al., 1992). After the first day of storage, CO₂ production was lower for coated strawberries than for the control with differences becoming more noticeable after the third day of storage. Between the coating concentrations applied, respiration rate was lower for fruit coated with 1.5% chitosan but no clear differences were found between samples coated with or without the addition of CaGlu. The respiration pattern for coated fruit differed from that of untreated fruit. The latter showed a slight increase in CO₂ production at the end of the storage period, which could be associated with fruit

<table>
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<tr>
<th>Storage days (d)</th>
<th>Temperature (°C)</th>
<th>Respiration rate (mgCO₂ kg⁻¹ h⁻¹)</th>
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<td></td>
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<tr>
<td>2</td>
<td>33</td>
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<td>6</td>
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The difference in respiration rate between two and six days 0.32 10.95
damage and fungal decay. For coated strawberries, the respiration rate showed a minimum on the third storage day and returned to values similar to those obtained after the first day. Internal gas atmosphere modification has been suggested to be the cause of reduced CO₂ production by coated fruits. In this regard, the gas barrier properties and perm selectivity (the ratio of PCO₂/PO₂ permeation coefficient) of the edible coating applied to the skin surface and their dependence on relative humidity and temperature will play an important role in the changes in endogenous O₂ and CO₂ levels. It is well known that excessive restriction of gas exchange can lead to anaerobiosis and the development of off-flavour. Chitosan coating has been reported to modify the internal atmosphere of tomatoes (El Ghaouth et al., 1992), Japanese pear (Du et al., 1997), strawberries (Perdones et al., 2012) and apples (Gemma and Du, 1998) by depletion of endogenous O₂ and a rise in CO₂ without achieving anaerobiosis.

External Colour

One of the important factors in the perception of strawberry fruit quality is the colour of the fruit. Coating treatments did not report significant changes in initial colour coordinates of fruit. It has been observed that uncoated fruits are significantly darker than coated fruit throughout the storage period. The chitosan concentration of the coating solution gave rise to significant differences in fruit colour. By the end of the storage period, surface colour of strawberries had decreased by around 27% for control fruit and by around 18% and 7% for fruit coated with 1% and 1.5% chitosan, respectively. Incorporation of calcium gluconate in the coating formulation did not apply any additional effect on delaying fruit darkening. Changes in the chroma value of the strawberry surface during storage develop a less bright colouration, as evidenced by lower values of chroma. The reduction in chroma values was significantly greater for uncoated fruit, and significant differences with respect to initial values were found after the second day of storage. As regards coated fruit, no significant differences were found among samples treated with different concentrations of chitosan. Changes in the chroma of coated fruit with storage time were slight and only became significant at the end of the storage period. Chroma was reduced by around 30% for control and 10% for coated fruit. The hue angle of uncoated strawberry began to decrease after the second day of storage and at the end of the storage period, the decline was 32%. The hue angle of coated fruit did not show any significant change during storage. Colour changes in harvested, fully red, ripe strawberries occur progressively during storage. Fruit darkens, skin colour becomes less chromatic and surface browning develops. Less red skin and darkening due to oxidative browning reactions have been found to be more marked in ripe strawberries that suffer greater moisture loss during storage (Nunes et al., 2005). The control of moisture loss by chitosan coatings contributes to minimizing external colour changes in fully ripe strawberries. Along with water loss, colour changes in strawberry fruit are greatly influenced by storage temperature. It is thus to be expected that colour differences between control and coated strawberries be more accentuated in fruit stored at higher temperatures. It is also reported that factors that could also have an influence on the development of dark-colored pigments include changes in ascorbic acid and in sugar profiles, peroxidase activity, and other phenolic compounds that are good substrates for enzymatic browning (Nunes et al., 2005).

Antibacterial Activity of Chitosan Solutions

Chitosan has been shown to have antibacterial activities on the growth of a wide variety of bacteria. Recently the in vitro antibacterial activity and mechanism of action of two kinds of acid-soluble chitosan and one water-soluble chitosan against apricot fruit rot pathogen Burkholderia seminalis has been observed (Lou et al., 2011). Generally, the inhibition activity of chitosan depends on the type, concentration, molecular weight and degree of deacetylation. It has been shown that acid-solution chitosan particularly chitosan A at a concentration of 2.0 mg/mL demonstrated strong inhibition activity against apricot fruit pathogen Burkholderia seminalis while as water-solution chitosan C has shown limited inhibition activity. The antibacterial activity and mechanism of action of acid-soluble chitosan has been explained based on membrane disruption, cell lysis, abnormal osmotic pressure, and additional chitosan coating around the bacteria based on integrity of cell membranes test, out membrane permeability assays and transmission electron microscopy observation. In addition, biofilm biomass was markedly reduced after treating with acid-soluble chitosan, indicating the importance of biofilm formation in the antibacterial mechanism of chitosan. Sanchez-Gonzalez et al. (2011a) developed antibacterial composite films based on chitosan or hydroxypropylmethylcellulose and different essential oils (lemon, tea tree or bergamot), which were applied on the surface of inoculated agar plates, which were used as a model of a solid food system. In this study, an inhibition of the growth of bacteria (Escherichia coli, Listeria monocytogenes and Staphylococcus aureus) was observed for chitosan films that incorporated essential oils. The antibacterial activity of the chitosan films have enhanced when the added essential oils were more effective than the polymer, like in the case of Gram-positive bacteria. Chitosan-essential oil edible coatings have proven to be effective at extending the shelf-life of some fruit and
vegetables, such as sweet pepper (Xing et al., 2011) and table grapes (Sanchez-Gonzalez et al., 2011b).

Conclusion

Because of numerous potential applications and properties, chitosan has gained lot of attention. Antibacterial, antifungal and film forming properties of chitosan make it an ideal for use as biodegradable antimicrobial packaging material to improve the storability of perishable fruits. The antimicrobial activity of chitosan against a wide range of food borne filamentous fungi, yeast, and bacteria has made it a potential food preservative. It is clearly demonstrated by numerous researches that chitosan can be used as an effective preservative or coating material for improvement of quality and shelf life of various fruits. It is clearly shown that chitosan, as a preservative material, could delay the ripening process by inhibiting the respiration rate in fruits. This suggests that chitosan not only maintains firmness but also improves the postharvest quality during cold storage and also suggests that chitosan is promising as an edible coating to be used in commercial postharvest applications for prolonging the storage life of fruits. Since chitosan application modified the respiration pattern of fruits, further research is underway to evaluate the effect of this treatment on the fruit flavor profile.

References


Wiles, J.L., Vergano, P.J., Barron, F.H., Bunn, J.M. and Testin, R.F.
Chitosan Edible Coating


