4.1 Introduction

A tremendous growth in the fresh cut industry has been witnessed in the past few decades, owing to increased demand for convenience foods and improved awareness about the health benefits of fruit and vegetable consumption.

Among the wide variety of minimally processed vegetables available, the consumption of fresh cut carrots as ready to eat carrot snacks or as salad vegetables are increasing in popularity (Barry–Ryan et al., 2000). Carrot is a nutritious tuber, considered as the major source of α and β carotenoids, and also other antioxidant nutrients such as polyphenols and vitamin C. They are also good to fair sources of fibre, potassium, group B vitamins, Vitamin D and E (O’Neill et al., 2001). The phytochemical compounds are considered to be responsible for protection against the harmful effect of reactive oxygen species, which in turn reduces the risk of diseases like CVD and cancer (Dillard and German, 2000).

Another fresh cut vegetable gaining wide popularity is radish. Radish roots are good sources of vitamin C, B-complex vitamins and minerals like manganese and phosphorus. They act as diuretics, anti scorbatic-agents, stimulate the digestive system and liver thereby promoting better digestion by increasing bile production. They are good sources of fibre and hence help in regulation of blood pressure, lowering blood cholesterol and reducing risk of heart diseases (Ramarathnam et al., 1997). Minimally processed radish is one of the important constituents in mixed salads to add flavor due to its strong and unique taste, and are increasing in demands in countries such as Brazil (del Aguila et al., 2006). It is also a popular starting material for preparing dehydrated products and pickles in Japan, China and Korea.
However, consumption and sales of these minimally processed vegetables are hindered because of deterioration during storage caused due to several reasons such as tissue wounding. These detrimental changes include browning, weight loss and increased susceptibility to microbial spoilage (Gonzalez-Aguilar, 2010). High respiration rate, development of off-flavors, acidification, reduced firmness, discoloration and microbial spoilage are some of the major problems associated with minimally processed carrots (Barry–Ryan et al., 2000). Radish shreds lose their marketability mainly due to browning and development of off-flavors. In a study reported by del Aguila et al., (2008) browning in fresh-cut radish could not be controlled even by use of antioxidants such as citric acid and ascorbic acid.

Research efforts are therefore, required to develop inexpensive and effective strategies that minimize such undesirable changes and to deliver safe and quality products with better shelf life stability to the consumers.

Several preservation technologies have been adopted to meet this requirement, some of them being physical decontamination methods like irradiation, electrolyzed water and ozone treatment and other techniques like use of cold chains, controlled and modified atmospheric storage (Corbo et al., 2010). Higher capital and maintenance costs associated with these techniques limits their wider application. Chemical sanitizers like chlorine, hydrogen peroxide and sulphites are also used but their application in fresh cut fruits and vegetables is being questioned from the perspective of safety and hence poses constraints on their use. The negative side effects combined with the pressure from consumers to limit the use of synthetic additives, have necessitated search for other safer alternatives.

Use of natural compounds of plant and animal origin is one of the emerging alternate technologies. The biodegradability and antimicrobial activity of these compounds has attracted the attention of researchers towards developing safe and environmental friendly techniques, utilizing application as an edible coating on fresh cut fruits and vegetables by these compounds. Chitosan is one such compound being extensively explored. Its application as an edible coating on fresh cut fruits and vegetables is due to its wide spectrum of antimicrobial activity, excellent coating ability, and biocompatibility (Shahidi et al., 1999).
Aloe vera gel is another polysaccharide with good coating efficiency and antifungal activity (Jasso de Rodriguez et al., 2005). Application of Aloe gel as edible coating has been explored only very recently. Studies have focused on fresh cut fruits such as apple slices (Chauhan et al., 2011), kiwifruit (Benitez et al., 2013), and pomegranate arils (Martinez-Romero et al., 2013). There is, however, paucity of studies on minimally processed vegetables and warrants exploration.

Literature indicates absence of edible coating studies using chitosan or Aloe gel on carrot and radish shreds. This chapter reports the effect of powder coating technique using Aloe gel and chitosan biopolymers on bioactive compounds and shelf life quality of carrot and radish shreds packed in macroperforated LDPE pouches.

4.2 Review of literature

4.2.1 Aloe gel edible coating studies on minimally processed fruits and vegetables

Limited studies have been conducted to study the effect of Aloe gel on minimally processed produce, as reviewed below.

In a study on fresh cut apples (Chauhan et al., 2011), ozonized apple slices pretreated with ascorbic acid, citric acid and sodium benzoate were coated with shellac and Aloe gel, separately and in combination. The authors reported reduction in respiration rate, ethylene synthesis and activity of enzymes like polyphenol oxidase, and peroxidase in the samples coated with Aloe gel and also AG combined with shellac. Better maintenance of color, firmness along with increased microbial and shelf life quality was also reported during storage.

Another recent study on fresh cut apples by Song et al. (2013), reported delayed browning, reduction in weight loss, better firmness and lower microbial load with Aloe gel coating at 50% concentration. Combination of Aloe gel with 0.5% cysteine was reported to be most effective in reducing browning and the microbial population.

A study by Yulianingsih et al., (2013), reported reduced weight loss, color changes and better firmness retention in minimally processed cantaloupe coated with
Aloe gel along with ascorbic acid, glycerol and carboxy methyl cellulose and stored for 4 days at different temperatures.

Martinez-Romero *et al.*, (2013), studied the effect of treatment with Aloe gel alone or in combination with ascorbic and citric acids on the quality and shelf life of ready to eat pomegranate arils. Aloe gel treated samples exhibited better quality in terms of lower respiration rate, better firmness retention, increased levels of total phenolics and total anthocyanins, lower microbial load and higher sensory acceptability.

Benitez *et al.*, (2013) coated fresh cut kiwifruit slices with 0-15% of commercially obtained *Aloe vera* gel, and stored under cold conditions. The coated fruits were found to have reduced respiration rate, lower mesophilic load, better firmness and improved shelf life quality, with 5% concentration giving optimum results.

### 4.2.2 Chitosan edible coating studies on minimally processed fruits and vegetables

Effectiveness of chitosan coating to extend the shelf life quality of few minimally processed produce has been studied and is reviewed below.

Fresh-cut Chinese water chestnut was treated with aqueous solutions of 0.5, 1 and 2g of chitosan, packed in trays over wrapped with plastic films and stored at 4°C (Pen and Jiang, 2003). Chitosan coating was reported to effectively delay development of disease and surface discoloration. The effects increased with increase in concentration.

Dong *et al.*, (2004) coated manually peeled litchi fruits with 0 to 3% aqueous solutions of chitosan and stored the fruits at -1°C. Chitosan coating was found to delay decline in sensory quality and weight loss. PPO and POD activities decreased during storage. After 6 days of storage coated samples had higher contents of TSS, titrable acidity and ascorbic acid content. Application of chitosan coating hence, was reported to extend the shelf life of peeled litchi fruits.
Effectiveness of 0, 0.5, and 2% aqueous chitosan solution coating for extending the shelf life of sliced mango was investigated by Chien et al., (2007). Manually sliced mangoes were placed in plastic trays over wrapped with PVDC films and stored at 6°C. Chitosan coatings delayed drop in sensory quality, prevented surface cracking and leaking of juice, thereby retarding weight loss after 7 days of storage. Treated samples had lower TSS, titrable acidity and higher ascorbic acid content and did not vary significantly with various concentrations. Chitosan coatings also delayed browning and inhibited the growth of microorganisms, maintaining the overall quality of sliced mango.

Eissa, (2007) studied the effect of chitosan coating on shelf life and quality of fresh cut mushroom. Fresh cut mushrooms treated with aqueous solutions of 0.5, and 2g/100ml, were placed in poly ethylene bags and stored at 4°C. Chitosan coating partially inhibited enzyme activity and delayed the increase in phenolic content in a concentration dependent manner thereby acting as an antibrowning agent during 15 days of storage and helped to retain the color. Samples coated with 2% showed high TSS, total acidity and a greater decrease in bacterial and fungal activity.

Gonzalez-Aguilar et al., (2009) studied the effect of 0.01 and 0.02g/ml chitosan coating on the quality of fresh-cut papaya cubes stored at 5°C. Medium molecular weight chitosan at 0.02g/ml was found to be effective by reducing microbial growth and by retaining color and firmness.

Xiao et al., (2010) studied the combined effects of pure oxygen pretreatment (PO) and chitosan coating (C) containing 0.03% rosemary extracts (R) on the quality of fresh-cut pears stored at 20°C for 3 days. They found that (PO) + (C) and (PO) + (CR) inhibited polyphenols oxidase activity, delayed softening and weight loss and retained higher firmness and soluble solid contents. The (PO) + (CR) also increased beneficial effects like reduction in browning, maintaining higher polyphenols, vitamin C content and sensory attribute compared to (PO) + (C).
4.3 Materials and methods

4.3.1 Preparation of minimally processed vegetables

Radish roots (*Raphanus sativus*) were procured from the local market at Anantapur, Andhra Pradesh, India. Topped radishes free from physical and pathological damage were selected. Surface dirt was removed by washing the roots with tap water. The roots were disinfected by dipping in 0.4% sodium hypochlorite solution for 5 min, followed by rinsing under running water, draining and surface drying.

Medium sized carrots (*Daucus carota*) were procured from the local market. Carrots were initially washed under running tap water to remove surface dirt and soil contamination. Root tips and leaf ends were removed and carrots free from damage were selected for processing.

The carrot and radish roots were then peeled using a hand peeler and shredded using a vegetable shredder to obtain shreds of about 2-3 mm thickness and 35-40 mm length.

4.3.2 Selection of coating method

Generally, dip technique is used to coat fresh cut fruits and vegetables. However, large quantity of coating solution is required for complete immersion of the commodity and involves longer coating preparation time. Quality alteration occurs in the solution after single use and hence reuse of the coating is not possible. Spray coating is an alternative to dip coating. However, in fresh cut produce, leaching of pigments and nutrients from the surface into the dip or spray solution is observed. It also causes undesirable changes in taste and texture. Keeping in view the above drawbacks, powder coating was developed as an innovative alternative technique for coating carrot and radish shreds. This is less time consuming and requires lesser coating material.
4.3.3 Application of Aloe gel and chitosan powder coating on carrot and radish shreds

Purified chitosan powder prepared in the laboratory as described earlier, and spray dried Aloe gel powder (200X) obtained from Excel Industries, Hyderabad, India, were used as the coating agents.

Following the shredding operation, the carrot and radish shreds were divided into two batches of four lots I, II, III and IV. The first lot (I) served as control (KC for carrot and RC for radish). The remaining three batches of lots II, III and IV were spread as a thin layer (~2cm) in polypropylene trays. Different concentrations of Aloe gel and chitosan powder (0, 0.1%, 0.2% and 0.3%) were applied uniformly over the surface of the shreds, followed by thorough mixing to ensure adequate coating. The samples were coded based on the biopolymer and concentration used (Fig 4.1).

4.3.4 Packaging and storage

The packaging material found to be effective for storage of fresh cut fruits and vegetables is LDPE (Robertson, 2006). Modified atmosphere packaging (MAP) along with storage at low temperature is also recommended (Hirata et al., 1995). A simple, cost effective technique to achieve desirable gaseous diffusion across the packages is through the use of macro perforations that just involve punching of holes in the film package (Rai and Singh, 2012).

Hence, for studying the shelf life of uncoated control and coated vegetable shreds, the samples were distributed into sets of 100g x 7 each in macro perforated LDPE resealable pouches (15x13 cm; 0.6 mm thickness). Ventilation area of 8 cm² was provided, dispersed over the whole pouch by sixteen holes each of 0.5 cm diameter. The packages were stored at 10°C for 15 days and sampling was carried out at periodic intervals. Temperature of 10°C was chosen to simulate the conditions of the market cold shelves where these produce are stored prior to sales.
Figure 4.1: Flow chart of Aloe gel and chitosan powder coating on minimally processed carrot and radish

Carrots/radish roots

Washed, peeled & shredded (3-4mm)

Aloe gel (AG) powder coating
Conc. Carrot Radish
0.1% 0.1KAG 0.1RAG
0.2% 0.2KAG 0.2RAG
0.3% 0.3KAG 0.3RAG

Chitosan (CH) powder coating
Conc. Carrot Radish
0.1% 0.1KCH 0.1RCH
0.2% 0.2KCH 0.2RCH
0.3% 0.3KCH 0.3RCH

Control
Carrot – KC
Radish - RC

Packed in macroperforated LDPE pouches and stored at 10°C for 15 days
4.3.5 Analysis of coated minimally processed vegetables

4.3.5.1 Physico-chemical parameters

All the samples were periodically analyzed on the initial day and after 5, 10 and 15 days of storage for physiological loss in weight/PLW (%), titrable acidity (%), total soluble solids/TSS (°Brix), and respiration rate/RR (mmol CO$_2$/kg/s) using standard methods, as described in section 3.3. For the determination of PLW, model packages in triplicates were accurately weighed at periodic intervals throughout the storage period. The respiration rate of shreds samples (100 g) placed in 470 mL PET jar and sealed for 1h at 10 °C were analyzed using PBI Dansensor gas analyzer, (Checkmate II, Denmark) as described earlier. Moisture content was also estimated in the shred samples by AOAC method (1990).

For radish shreds, two additional procedures, namely juiciness index and exudate volume were devised since these were found to be important for consumer acceptance and marketability.

To quantify the juiciness index, juice was extracted from a weighed amount of sample using a hand-operated juicer and the volume of juice in mL was measured. The juiciness index was calculated with the following formula: Juiciness index (mL/kg) = 1000 x Y/X, where, Y= quantity of juice obtained (mL) and X= weight of sample taken (kg).

To estimate the volume of exudates, a weighed amount of sample from various treatments was placed on a strainer and allowed to drain for 10 min. The collected exudates was measured and reported in mL/kg.

4.3.5.2 Instrumental color analysis

The test sample was placed in a 3 inch diameter petri plate, which was completely filled with the sample. The color of the samples was measured using a color reader (Konica MINOLTA CR-10), using the Hunter L*, a* b* units, where L* indicates luminosity or brightness, a* corresponds to greenness (-)/ redness (+) and b* corresponds to blueness (-)/ yellowness (+). The L*, a* and b* data
were transformed to chroma value \[CV= (a^*^2+b^*^2)^0.5\] and used to trace the color changes in carrot shreds. Whiteness index was computed using the formula:

\[WI= \{100 [(100-L2) +a2+b2]0.5\}.

This was used to reflect degree of browning in radish shreds. A total of 27 measurements were carried out per sample, taking 9 readings from different sites of each sample in three different batches.

4.3.5.3 Microbial analysis

Total mesophilic aerobic bacterial count (TBC) and total yeast and mold counts (YMC) of the samples were determined using Plate Count Agar (PCA) and Potato Dextrose Agar (PDA) supplemented with chloramphenicol, respectively. The plates were incubated at 35\(\pm2\)\(^{\circ}\)C for TBC and 28\(\pm2\)\(^{\circ}\)C for YMC for 24 h and 48 h, respectively. At the end of incubation period, the microbial colonies obtained were counted and reported in log CFU/g.

4.3.5.4 Sensory acceptability

The samples were subjected to sensory acceptability evaluation on initial and final day of storage (15d) by a group of 10 female panel members (selected from the investigator’s department) who were familiarized with the scoring system. Coded samples were presented to the panelists in a randomized manner. In order to reflect consumer acceptability, the panel was not specifically trained.

The panelists were asked to rate the samples on a five point hedonic rating scale for color, flavor, texture and overall acceptability, where 5 and 1 represented the highest and lowest acceptability scores, respectively. A score below three was considered to be the limit of marketability.

4.3.5.5 Phytochemicals and antioxidant activity

A direct colorimetric method as given by Ranganna (1986) was used for the estimation of vitamin C content. The top clear alcohol layer of the extracts obtained was read at 520 nm using isoamyl alcohol as blank. A calibration curve was prepared from solutions of ascorbic acid at concentrations 0.5-2 g/L.
Methanol extractions of fresh samples were carried out using a modified method of Banerjee et al. (2008). The fresh samples (5g) were extracted twice with aqueous methanol (50% V/V) for 18h at room temperature, followed by centrifugation at 3000 rpm for 10 minutes. The supernatants were combined and volumes made up to 50 ml.

These extracts were used for the estimation of total polyphenols (Folin-Ciocalteau method, Kahkonen et al., 1999), total flavanoids (Kosalec et al., 2004), and antioxidant activity in terms of DPPH radical scavenging assay (Brand-Williams et al., 1995) ferric reducing antioxidant power (FRAP) (Benzie and Strain, 1999) and reducing power (Oyaizu, 1986), as per the procedures described in chapter 2, section 2.2.

4.3.5.6 Statistical analysis

Results are expressed as means of three independent trials. Experimental data were processed by one-way ANOVA using the least significant difference (LSD) as a multiple range test, by setting the statistical significance at 95% level. Analysis was conducted using SPSS software (SPSS Student Version 16.0 for windows).

4.4 Results and discussion

4.4.1 Effect of biopolymer coatings on weight loss of carrot and radish shreds

Physiological loss in weight (PLW) was found to increase on storage for both carrot and radish shreds samples (Fig 4.2). Highest weight loss was witnessed in respective control samples, KC (13.5%) and RC (12.5%). Shreds coated with 0.2% and 0.3% Aloe gel and chitosan recorded lower PLW. The PLW of 0.3KCH (9.17%) and 0.3KAG (9.34%) was found to be 32% and 31% lower than the control (KC-13.4%) at the end of storage period. Similarly for radish, 0.3RAG (6.12%) and 0.3RCH (6.18%) recorded 46.8% and 44% lower PLW compared to RC (51.1%), respectively.
Fig. 4.2 Effect of different biopolymer coatings on the physiological loss in weight (%) of carrot (a) and radish (b) shreds

KC and RC- Uncoated carrot and radish samples
0.1KAG, 0.2KAG, 0.3KAG Carrot samples, and 0.1 RAG, 0.2RAG, 0.3RAG Radish samples coated with 0.1%, 0.2%, 0.3% Aloe gel powder, respectively
0.1 KCH, 0.2KCH, 0.3KCH Carrot samples, and 0.1 RCH, 0.2RCH, 0.3RCH Radish samples coated with 0.1%, 0.2%, 0.3% chitosan powder, respectively
Moisture content of the samples reduced on storage which corresponded to the loss in weight. Significantly higher moisture was recorded in the samples coated with 0.2% and 0.3% chitosan and Aloe gel, in both carrot and radish shreds.

Xiao et al., (2010), have also reported reduced weight loss in fresh cut pears coated with chitosan solution. This effect could be attributed to the hydrating and gel forming property of chitosan which forms a coating on the fruit surface. Chitosan, thus, acts as a water vapour barrier by preventing moisture migration to the environment. The prevention of water loss from the surface by treatment with chitosan has also been demonstrated in peeled litchi fruits (Dong et al., 2004). Effect of Aloe gel in preventing weight loss has been demonstrated in Aloe gel and shellac coated apple slices, which was attributed to the high water barrier efficiency of the polysaccharide and lipid based coating (Chauhan et al., 2011)

4.4.2 Effect of biopolymer coatings on TA and TSS of carrot and radish shreds

Minimal changes were witnessed in the titrable acidity and TSS of the 0.2% and 0.3% biopolymer coated carrot and radish shreds, demonstrating the effectiveness of the coatings in maintaining the initial quality. Control samples KC and RC recorded significantly higher TA of 0.41 and 0.62 at the end of 15d storage period, respectively (Fig 4.3 and 4.4).

In a study by Alegria et al., (2010) on fresh cut carrots, an increase in pH and corresponding reduction in acidity were observed. This was correlated to an increased production of LAB and their fermentation by products like lactic and acetic acids. A similar observation was also made in the present study, wherein, the microbial load of the control samples was higher compared to treated samples.

Similarly, the TSS content of the control samples recorded significantly higher value of 8.5 and 1.73 for KC and RC, respectively. An increase in TSS was seen in both samples on storage. This is attributed to increased metabolic activity resulting in the conversion of starch to sugars (Ayhan et al., 2008).
Fig 4.3: Effect of different biopolymer coatings on the titrable acidity (%) of carrot (a) and radish (b) shreds

KC and RC- Uncoated carrot and radish samples
0.1KAG, 0.2KAG, 0.3KAG Carrot samples, and 0.1 RAG, 0.2RAG, 0.3RAG Radish samples coated with 0.1%, 0.2%, 0.3% Aloe gel powder, respectively
0.1 KCH, 0.2KCH, 0.3KCH Carrot samples, and 0.1 RCH, 0.2RCH, 0.3RCH Radish samples coated with 0.1%, 0.2%, 0.3% chitosan powder, respectively
**Fig 4.4: Effect of different biopolymer coatings on the total soluble solids (°Brix) of carrot (a) and radish (b) shreds**

KC and RC - Uncoated carrot and radish samples
0.1KAG, 0.2KAG, 0.3KAG Carrot samples, and 0.1 RAG, 0.2RAG, 0.3RAG Radish samples coated with 0.1%, 0.2%, 0.3% Aloe gel powder, respectively
0.1 KCH, 0.2KCH, 0.3KCH Carrot samples, and 0.1 RCH, 0.2RCH, 0.3RCH Radish samples coated with 0.1%, 0.2%, 0.3% chitosan powder, respectively
In carrot samples, 0.3KAG samples showed significantly lower TSS of 7.53, whereas, in radish shreds 0.3RAG and 0.3RCH samples recorded lowest TSS of 1.23 and 1.2, respectively, at the end of 15d storage period, significantly lower than the control samples. Concentration of solids due to the higher degree of drying observed in the control sample could also be responsible for increased soluble solids content.

4.4.3 Effect of the biopolymer coatings on juiciness index and exudates volume in radish shreds

Additional marketability related parameters were evaluated in radish shreds i.e. juiciness index and exudates volume (Fig. 4.5). A decrease in juiciness index (JI) was witnessed in the samples on storage, with a corresponding increase in the exudates volume (EV). Significantly lower JI of 26.5 and significantly higher EV of 28.7 was seen in the RC samples, compared to the coated samples.

The coatings exhibited a beneficial effect on maintaining the JI and thereby causing a reduction in the EV. Highest JI of 39.6 was seen in the 0.3RAG samples closely followed by 0.3RCH (38.2). Correspondingly, significantly lower EV values were also recorded in 0.3RAG and 0.3RCH samples (17.2 and 18.7), respectively.

It was observed that after few hours of coating, the control samples were wetter, whereas, the hygroscopic biopolymer powders absorbed the exudate in the treated samples. The biopolymer powders were therefore found to swell up forming a gelatinous layer coating the samples thoroughly. This could explain the beneficial effects of reduced respiration rate, lower moisture loss, good wet crispness of the shreds due to reduced mushiness, thus minimizing the primary causes of spoilage.

Similar results have also been reported in sliced mango fruit (Chien et al., 2007) and peeled litchi fruit (Dong et al., 2004) wherein chitosan treatment prevented leakage of juices from the surface and maintaining freshness for a longer time.
Fig 4.5: Effect of different biopolymer coatings on the juiciness index (a) and exudates volume (b) of radish shreds

RC- Uncoated radish samples; 0.1 RAG, 0.2RAG, 0.3RAG - Radish samples coated with 0.1%, 0.2%, 0.3% Aloe gel powder; 0.1 RCH, 0.2RCH, 0.3RCH - Radish samples coated with 0.1%, 0.2%, 0.3% chitosan powder, respectively
4.4.4 Effect of the biopolymer coatings on respiration rate of carrot and radish shreds

The initial respiration rate of carrot shreds was found to range from 0.42-0.49 mmol CO₂/kg/s, whereas, for radish shreds a higher RR ranging from 12.5-16 mmol CO₂/kg/s was recorded (Fig 4.6). A reduction in respiration rate was observed in all the samples on storage. Similar observations have also been reported by delAguila et al., (2006). This has been postulated to be due to the cessation of reaction of the respiratory substrates with the cell enzymes present on the surface of the fresh cut produce.

Samples coated with higher concentrations of Aloe gel and chitosan i.e. 0.2 and 0.3 KAG and KCH, recorded significantly lower respiration rate compared to the untreated samples. This demonstrated the potential of Aloe gel and chitosan coating in reducing the respiration rate of the shreds, and thereby maintaining the quality for longer period.

Similar observations have also been made by Qi et al., (2011) for fresh cut apple slices treated with chitosan. The water insolubility and oxygen barrier property of chitosan has been hypothesized to create an internal modified atmosphere within the commodity, thereby causing a reduced respiration rate. A reduced respiration rate following Aloe gel coating has been reported for ready to eat pomegranate arils (Martinez-Romero et al., 2013).

4.4.5 Effect of the biopolymer coatings on color of carrot shreds and radish shreds

Chroma value of the carrot shreds was found to reduce on storage from an initial value ranging from 30.9 to 31.9 (Fig 4.7). The decrease was more pronounced in the control and 0.1% biopolymer coated samples. An 18.1% and 14.8% higher chroma value was seen in 0.3 KAG and 0.3% KCH samples compared to control at the end of storage period, indicating better retention of color in the coated samples.
Fig 4.6 Effect of different biopolymer coatings on the respiration rate (mmol CO₂/kg/s) of carrot (a) and radish (b) shreds

KC and RC- Uncoated carrot and radish samples
0.1KAG, 0.2KAG, 0.3KAG Carrot samples, and 0.1 RAG, 0.2RAG, 0.3RAG Radish samples coated with 0.1%, 0.2%, 0.3% Aloe gel powder, respectively
0.1 KCH, 0.2KCH, 0.3KCH Carrot samples, and 0.1 RCH, 0.2RCH, 0.3RCH Radish samples coated with 0.1%, 0.2%, 0.3% chitosan powder, respectively
Fig 4.7: Effect of different biopolymer coatings on the chroma value of carrot shreds (a) and whiteness index of radish shreds (b)

KC and RC- Uncoated carrot and radish samples
0.1KAG, 0.2KAG, 0.3KAG Carrot samples, and 0.1 RAG, 0.2RAG, 0.3RAG Radish samples coated with 0.1%, 0.2%, 0.3% Aloe gel powder, respectively
0.1 KCH, 0.2KCH, 0.3KCH Carrot samples, and 0.1 RCH, 0.2RCH, 0.3RCH Radish samples coated with 0.1%, 0.2%, 0.3% chitosan powder, respectively
Dehydration of outer tissue layers has been indicated to be a major cause of surface discoloration (Cisneros-Zevallos et al., 1995), which is detrimental to the quality of shredded carrots as it results in whitening and formation of lignin (Howard and Griffin, 1993). Better moisture retention in the coated samples over control could have aided in keeping the plant tissue surface wet and thereby prevented surface discoloration. Similar observations have also been made by Vargas et al., (2009) in chitosan coated carrot slices.

For radish, whiteness index (WI) was measured which showed a declining trend on storage. An initial WI ranging between 51 and 52 was found to reduce to 37.5 in the RC samples, significantly lower than the other biopolymer coated samples. Highest WI of 40.7 and 39 was recorded in 0.3RAG and 0.3RCH samples after 15d of storage, respectively.

Inhibition of polyphenol oxidase (PPO) and peroxidase (POD) enzymes that cause browning has been reported in Aloe gel coated apple slices (Chauhan et al., 2011) and chitosan coated mushrooms (Eissa, 2007). Hence, the PPO and POD enzyme inhibitory effect of the selected biopolymers reported in the above studies could be attributed to the lower degree of browning and higher WI in radish shreds.

4.4.5 Effect of the biopolymer coatings on microbial quality of carrot and radish shreds

Microbial quality of the carrot and radish shreds samples was evaluated on the 0d and 15d of storage. Significant differences were observed among the samples on the initial day itself with regard to both total bacterial count and yeast and mold count (Fig 4.8 a and b). The control samples KC and RC showed an increase in TBC and YMC on storage. On the other hand, all the biopolymer coated samples showed a significant reduction in the microbial counts on storage, the effect being more pronounced in case of samples coated with higher concentration of the biopolymers (0.3KAG, 0.3KCG, 0.3RAG and 0.3RCH).
Fig 4.8a: Effect of different biopolymer coatings on the total bacterial count (log CFU/g) of carrot (i) and radish (ii) shreds

KC and RC - Uncoated carrot and radish samples
0.1KAG, 0.2KAG, 0.3KAG Carrot samples, and 0.1 RAG, 0.2RAG, 0.3RAG Radish samples coated with 0.1%, 0.2%, 0.3% Aloe gel powder, respectively
0.1 KCH, 0.2KCH, 0.3KCH Carrot samples, and 0.1 RCH, 0.2RCH, 0.3RCH Radish samples coated with 0.1%, 0.2%, 0.3% chitosan powder, respectively
Fig 4.8b: Effect of different biopolymer coatings on the yeast and mold count (log CFU/g) of carrot (i) and radish (ii) shreds

KC and RC- Uncoated carrot and radish samples
0.1KAG, 0.2KAG, 0.3KAG Carrot samples, and 0.1 RAG, 0.2RAG, 0.3RAG Radish samples coated with 0.1%, 0.2%, 0.3% Aloe gel powder, respectively
0.1 KCH, 0.2KCH, 0.3KCH Carrot samples, and 0.1 RCH, 0.2RCH, 0.3RCH Radish samples coated with 0.1%, 0.2%, 0.3% chitosan powder, respectively
A study conducted by Durango et al., (2006) supported the findings of the present study, reporting that chitosan coating on minimally processed carrots brought about a reduction of 1.3 logCFU/g in mesophilic aerobic count. Antimicrobial activity of Aloe gel has also been demonstrated when applied as a coating on pomegranate arils (Martinez-Romero et al., 2013).

Among the biopolymers, AG coated samples showed slightly better activity against yeast and molds compared to CH coated samples, which showed better action against bacteria. The better microbial quality observed for AG and CH coated samples could be attributed to their wide antimicrobial activity reported against different microorganisms (Jasso de Rodriguez et al., 2005; Rabea et al., 2003). One of the mechanisms proposed to describe the antimicrobial activity of chitosan is the interaction between positively charged amino groups present in chitosan with the negatively charged microbial cell membranes, leading to the leakage of intracellular constituents of the microorganisms (Dutta et al., 2009). In case of Aloe gel, however, no such mechanism has been reported and the antimicrobial activity is attributed to the presence of a number of antimicrobial compounds such as saponins, acemannan and other anthraquinone derivatives (Martinez – Romero et al., 2006).

4.4.6 Effect of the biopolymer coatings on sensory acceptability of carrot and radish shreds

Carrot and radish shreds evaluated on the initial day revealed all samples to have similar sensory acceptability (Fig. 4.9 a and b). The control samples were found to become unacceptable after one week of storage. At the end of 15d storage period, the samples coated with 0.2% AG and CH showed highest acceptability followed by 0.3% biopolymer coated samples.

In case of radish shreds, the critical sensory characteristics that affect the marketability were identified as browning and undesirable flavor changes. For carrot shreds, the critical sensory characteristics that affect the marketability of carrot shreds were identified as surface dryness, change in the fresh orange red colour, development of bitter aftertaste and flavor.
Fig 4.9a: Effect of different biopolymer coatings on sensory acceptability of carrot shreds on 0d (i) and 15d (ii) of storage

KC - Uncoated carrot samples
0.1KAG, 0.2KAG, 0.3KAG Carrot samples, and 0.1 RAG, 0.2RAG, 0.3RAG Radish samples coated with 0.1%, 0.2%, 0.3% Aloe gel powder, respectively
0.1 KCH, 0.2KCH, 0.3KCH Carrot samples, and 0.1 RCH, 0.2RCH, 0.3RCH Radish samples coated with 0.1%, 0.2%, 0.3% chitosan powder, respectively
Fig 4.9b: Effect of different biopolymer coatings on sensory acceptability of radish shreds on 0d (i) and 15d (ii) of storage

KC and RC- Uncoated carrot and radish samples
0.1KAG, 0.2KAG, 0.3KAG Carrot samples, and 0.1 RAG, 0.2RAG, 0.3RAG Radish samples coated with 0.1%, 0.2%, 0.3% Aloe gel powder, respectively
0.1 KCH, 0.2KCH, 0.3KCH Carrot samples, and 0.1 RCH, 0.2RCH, 0.3RCH Radish samples coated with 0.1%, 0.2%, 0.3% chitosan powder, respectively
The results indicated Ag and CH powder coating at 0.2% to be more suitable for extending the acceptability and marketability of carrot and radish shreds by almost one week period.

4.4.7 Effect of biopolymer coatings on vitamin C levels of carrot and radish shreds

Based on the physico-chemical, microbial and sensory acceptability data, samples treated with 0.2% AG and CH resulted in optimum quality and were analyzed for phytochemicals.

Initial vitamin C content of the carrot and radish shreds samples was found to range from 2.01-2.09 mg/100g and 14.25-14.75 mg/100g, respectively (Fig. 4.10). A gradual decrease in ascorbic acid content during storage was observed, which could be attributed to the stress induced during shredding operation. This could have in turn caused an increase in activity of ascorbate oxidase and polyphenol oxidase, which promote the conversion of ascorbic acid to dehydroascorbic acid (Lee and Kader, 2000).

The biopolymer coated samples, however, maintained higher vitamin C. In carrots, 0.2KAG and 0.2KCH samples showed 75.7% and 72.5% higher vitamin C content after 15d storage compared to KC. In case of radish, 52.4% and 53.7% higher vitamin C content was found in 0.2RAG and 0.2RCH samples, respectively.

Better retention of vitamin C has been also demonstrated in chitosan coated fresh cut chestnut, mango and pear (Pen and Jiang, 2003; Chien et al., 2007; Xiao et al., 2010). This has been related to the reduced respiration rate as a result of coating treatment (Jiang and Li, 2001).

4.4.8 Effect of biopolymer coatings on total polyphenols (mg/100g) and flavonoids (mg/100g) of carrot and radish shreds

Initial polyphenol content of the carrot shreds was found to range from 2.53-2.55 mg/100g (Fig 4.11). For radish shreds, all samples recorded similar content of 6.09 g/100g.
Fig 4.10: Effect of different biopolymer coatings on vitamin C content (mg /100g) of carrot (a) and radish (b) shreds

KC and RC- Uncoated carrot and radish samples
0.2KAG Carrot samples and 0.2RAG Radish samples coated with 0.2% Aloe gel powder, respectively
0.2KCH Carrot samples and 0.2RCH Radish samples coated with 0.2% chitosan powder, respectively
**Fig 4.11:** Effect of different biopolymer coatings on total flavonoids (mg/100g) of carrot (a) and radish (b) shreds

- **KC and RC-** Uncoated carrot and radish samples
- **0.2KAG** Carrot samples and **0.2RAG** Radish samples coated with 0.2% Aloe gel powder, respectively
- **0.2KCH** Carrot samples and **0.2RCH** Radish samples coated with 0.2% chitosan powder, respectively
Fig 4.12: Effect of different biopolymer coatings on total polyphenols (mg/100g) of carrot (a) and radish (b) shreds

KC and RC- Uncoated carrot and radish samples
0.2KAG Carrot samples and 0.2RAG Radish samples coated with 0.2% Aloe gel powder, respectively
0.2KCH Carrot samples and 0.2RCH Radish samples coated with 0.2% chitosan powder, respectively
On storage, an increase was witnessed in the both the shreds samples, which was more pronounced in case of the biopolymer coated samples. Highest polyphenol content of 7.12mg/100g and 19.8mg/100g was recorded in 0.2KCH and 0.2RCH samples, respectively at the end of storage period. Similarly in case of flavonoids, an increase on storage was seen in the samples with the maximum content being recorded in 0.2RCH (12.3g/100g) and 0.2KCH (1.98g/100g) compared to their respective control samples RC (8.45g/100g) and KC (1.84g/100g) (Fig 4.12).

Increase in phenolic content in chitosan treated samples has been reported in tomato fruit (Liu et al., 2007) and apricot (Ghasemnezhad et al., 2010). A study on peeled lychee fruit coated with chitosan (Jiang et al., 2005) attributed this increase to the inhibition of the enzyme polyphenol oxidase, which causes degradation of anthocyanins and increased browning in fresh cut produce. An increase in total phenolics has also been reported for Aloe gel coated pomegranate arils on storage (Martinez Romero et al., 2013).

4.4.9 Effect of the selected biopolymer coatings on total antioxidant activity of carrot and radish shreds

Analysis of antioxidant activity of carrot and radish shreds was carried out periodically in terms of DPPH RSA, FRAP and reducing power.

After 15d of storage, significantly higher DPPH radical scavenging activity (RSA) of 30.5% and 32.5% was seen in 0.2RAG and 0.2RCH samples, respectively (Fig. 4.13).

Similarly, 0.2KAG and 0.2KCH coated carrot shreds recorded significantly higher DPPH RSA of 28.6% and 30.4%, respectively, after 15d storage compared to KC (23.6%). FRAP values also increased on storage. 0.2KAG and 0.2KCH coated carrot shreds showed 16.1% and 17.8% higher FRAP, respectively, and 0.2RAG and 0.2RCH radish shreds recorded 7.8% and 11.7% higher FRAP value than control, respectively, on storage (Fig. 4.14).
Fig 4.13: Effect of different biopolymer coatings on DPPH RSA (%) of carrot (a) and radish (b) shreds

Fig 4.14: Effect of different biopolymer coatings on FRAP (µ mol Fe²⁺/100g) of carrot (a) and radish (b) shreds

KC and RC- Uncoated carrot and radish samples
0.2KAG Carrot samples and 0.2RAG Radish samples coated with 0.2% Aloe gel powder, respectively
0.2KCH Carrot samples and 0.2RCH Radish samples coated with 0.2% chitosan powder, respectively
Fig 4.15a: Effect of different biopolymer coatings on reducing power of carrot shreds on 0d (i) and 15d (ii) of storage

Fig 4.15b: Effect of different biopolymer coatings on reducing power of radish shreds on 0d (i) and 15d (ii) of storage

KC and RC- Uncoated carrot and radish samples
0.2KAG Carrot samples and 0.2RAG Radish samples coated with 0.2% Aloe gel powder, respectively
0.2KCH Carrot samples and 0.2RCH Radish samples coated with 0.2% chitosan powder, respectively
The study revealed both AG and CH coated samples to have higher reducing power compared to control (Fig 4.15 a and b). An increase in reducing power was observed in all samples on storage, with higher RP recorded in samples coated with higher concentration of Aloe gel and chitosan.

Higher antioxidant potential observed in the biopolymer coated samples could be attributed to the good antioxidant activity reported for both Aloe gel (Hu et al., 2003) and chitosan (Xie et al., 2001; Anraku et al., 2011). Higher levels of bioactive compounds in coated samples could be the other contributing factor as a positive association was observed between the bioactive compounds and antioxidant activity in the biopolymer coated samples.

4.5 Conclusions

The present study thus demonstrated that Aloe gel and chitosan biopolymers could effectively improve the shelf life of fresh cut produce.

Powder coating technique explored was found to be appropriate and highly beneficial in terms of time consumed, quantity of coating material used, simplicity of technique and acceptability. Powder coatings using salt, sugar and other compounds have been reported for processed foods like potato chips, popcorn and candies mainly to impart flavor and colour (Khan et al., 2012). Electrostatic powder coating using cellulose and natamycin has been reported to improve shelf life of freshly shredded cheese (Elayedath and Barringer, 2002).

AG and CH coating also resulted in the elicitation of phytochemicals resulting in greater antioxidant potential of the coated samples and hence improved their health functionality.