Chapter 3

Efficacy of Aloe gel and chitosan biopolymer coating on postharvest quality and shelf life of whole fruits

3.1 Introduction

Fruits and vegetables play a major role in human nutrition, particularly through the supply of nutrients that are deficient in other food materials. Vitamins, minerals and bulk of dietary fibre are contributed by fruits and vegetables in the diet. They are also rich in flavonoids, carotenoids and other phytochemicals which have been reported to exhibit numerous pharmacological and therapeutic effects (Chavan and Patil, 2013).

India endowed with diverse agro-climatic conditions, produces a wide variety of fruits and vegetables such as tropical, subtropical, temperate and arid and hence enjoys an enviable position in the horticulture map of the world (www.indiaagronet.com). India is one of the largest producers of fruits and vegetables in the world and occupies second position after China, accounting for about 10.4 per cent of all fruits and nearly 40 per cent of tropical fruits produced globally. Fruit production in India has steadily increased from 36 to 47 million tonnes, between 1995 and 2004 (FAOSTAT, 2005).

Whole fruits and vegetables are highly perishable commodities and undergo huge postharvest losses. It has been estimated that these losses are as high as 50-60% in developing countries (Gustavsson et al., 2011). Reasons for these losses include physiological changes such as transpirational loss, improper storage temperature and relative humidity and physical injuries during handling. Since fresh fruits and vegetables are living commodities, they continue to respire in the postharvest state, which leads to ripening, senescence and microbial spoilage (Sharma and Singh, 2000; Kader, 2002).

Tomato is the second most consumed vegetable in the world after potato, (FAO, 2011). India is the second largest producer of tomatoes after China (FAOSTAT, 2005). It is valued for its color, flavor and taste and used in vegetable and spicy culinary.
Tomatoes and tomato products are rich source of folate, flavonoids and potassium (Leonardi et al., 2000). It contains a large amount of the pigment lycopene which imparts the characteristic red color to the fruit. Dietary intake of food containing lycopene (Agarwal and Rao, 2000) and consumption of tomato products (Weisburger, 2002) has been linked to protection against cancer and cardiovascular diseases.

Marketing of fresh tomato during the season is a great problem because it has a limited shelf life at ambient condition and is highly perishable, leading to huge postharvest losses. Several technologies have been explored in tomatoes to minimize these losses such as hyperbaric pressure treatment (Liplap et al., 2013), pre cooling treatment (Shahi et al., 2012), and heat treatment with modified atmospheric packaging (Ali et al., 2004). Recent studies have also explored the extension of shelf life of tomatoes through molecular genetics by increasing the levels of polyamines (Mattoo, 2011). However, the high capital investment and maintenance cost of these approaches limits their utilization. Low temperature storage has also been used for shelf life extension of tomato but it leads to chilling injury (Biswas et al., 2012).

Figs (Ficus carica L.) are one of the oldest cultivated subtropical fruits. Figs are delicious, wholesome, and nutritious. It is rich in fibre, calcium, potassium, iron, copper, manganese and magnesium (Chavan and Patil, 2013). The fleshy fruit is consumed fresh or in processed form, the dried form being the most popular. Figs are utilized for making products such as fig syrups, jellies, jams, spiced or pickled figs in the commercial sector (Woodroff, 1986). Fig is moderately important world crop with an estimated annual production of one million tons of fruit of which about 30% is produced by Turkey. The other major producers are Egypt, Morocco, Greece, California, Italy, Algeria, Syria and Tunisia. In India, fig is considered to be a minor fruit crop and the commercial cultivation of common (edible) fig is mostly confined to Western parts of Maharashtra, Gujarat, Uttar Pradesh (Lucknow and Saharanpur), Karnataka (Bellary, Chitradurga and Srirangapatna) and Tamil Nadu (Coimbatore) (www.agricultureinformation.com).

Fig is classified as a climacteric fruit, and to a little extent ripening continues once the fruit is harvested. Fresh market figs must be harvested when almost fully ripe to be of good eating quality. Owing to perishable nature of fruits, growers prefer to sell their
produce in local or nearby markets. Figs can be held only for a short period (7-10 days), at 0 °C and 85-90 % relative humidity. There is a growing interest to consume fresh figs in many countries. Also the local farmers and sellers incur a high postharvest loss of fresh fig fruits due to its perishable nature.

Fresh figs’ skin color and flesh firmness are related to their quality and postharvest life. Flavor is influenced by stage of ripeness and overripe figs can become undesirable due to fermentative products. Shrivelng of the skin and decay are other postharvest problems. Various chemical treatments such as chlorine (Karabulut et al, 2009) and sulphur dioxide (Cantin et al., 2011) have been used to improve the shelf life and to arrest the decay of figs. Controlled atmospheric storage has been also explored as an alternative storage method. But, this is not always feasible for small farmers to use and also results in development of off flavours due to ethanol accumulation (Colelli et al., 1991).

Techniques such as individual seal packaging with high density polyethylene film (Risse et al., 1987) and waxing (Segall et al., 1974) have been explored in general for fruits. However, drawbacks such as condensation of water in the seal-packed commodity promoting fungal growth (Miller et al., 1983) and ineffectiveness of using wax coating without fungicides (Ben-Yehoshua et al., 1979) have been encountered. Another widely used method to reduce postharvest losses is use of synthetic fungicides but increasing consumer awareness on the ill effects of pesticide residues in foods have led to a search for healthy and eco-friendly alternative.

One of the recently explored techniques to reduce postharvest losses in whole fruits and vegetables is through the use of edible coatings. Edible coatings may be defined as a thin layer of material that covers the surface of the food and serves as a barrier to moisture, oxygen and food solute movement (Nisperos-Carriedo, 1994).

The characteristics required for edible films and coatings depend mainly on the food product, which is to be coated. In fruits and vegetables, for example, the property of selective mass transfer is desirable, to allow fruit and vegetable respiration even while limiting their dehydration during storage (Kurte et al., 1994). Besides the barrier
efficiency, edible films and coatings have to be organoleptically and functionally compatible with foods.

Several attempts have been made to develop edible coatings and films by using materials derived from renewable sources. The utility of the edible coatings mainly lies in their capacity to act as an adjunct for improving overall quality, extending shelf life, improving economic efficiency and reducing the environmental burden associated with synthetic packaging materials. Naturally occurring biopolymers are much in demand for functioning as edible coatings.

Among the various biopolymers used as edible coating, gel obtained from the leaves of Aloe barbadensis Miller plant and chitosan, obtained as a marine industry waste have been explored to extend shelf life of fruits and vegetables. Aloe gel has been explored very recently for minimizing postharvest losses of fresh fruits and vegetables (Valverde et al., 2005), whereas, chitosan is a well researched coating material (No et al., 2007).

There are, however, absence or limited scientific reports on the efficacy of Aloe gel and chitosan coating on tomato and fig fruits. Also, in many reports commercially obtained Aloe gel/chitosan powder has been used, which are not cost efficient. Thus, the present study attempted to compare minimally processed biopolymer coatings prepared in the laboratory with those available commercially. Further, the performance of Aloe gel and chitosan coatings under market conditions has not been evaluated. Hence, market simulation studies were conducted on the coated fruits after the storage period.

3.2 Review of Literature

3.2.1 Types of edible coatings

3.2.1.1 Polysaccharide based coatings

Several polysaccharides are being widely used in coating formulations, which includes starch and its derivatives pectin, cellulose and its derivatives, alginate, carrageenan and several plant and microbial gums (Li and Yu, 2001). These coatings possess a hydrophilic nature and hence do not retard moisture loss, but exhibit excellent gas barrier property. This gas barrier function shown by these
coatings has been reported to be due to their tightly packed, organized hydrogen bonded network structure (Forssel et al., 2002).

Some interesting polysaccharides are being explored for their edible coating efficacy, and chitosan and Aloe vera gel are two of them. Chitosan coating has been reported to modify the internal atmosphere of the coated commodity without causing anaerobic respiration (Bai et al., 1988) and also have potent fungistatic activity (Goy et al., 2009). This in turn delays the physiological processes in the coated produce, prevents decay and thereby extends its shelf life. Aloe gel has been very recently explored as a coating and has been reported to exhibit prevention of moisture loss, maintenance of firmness and reduction of decay in the produce studied (Valverde et al., 2005).

3.2.1.2 Lipid based coatings

Lipids that have been used for the formulation of edible coating include bee wax, mineral oil, vegetable oil, surfactants, acetylated monoglycerides, waxes, shellac and other resin based coatings. These coatings exhibit minimum oxygen barrier property but have good water vapor resistance (Kester and Fennema, 1986). Some of the waxes such as carnauba wax, bee wax, paraffin wax have been used as edible coatings for many decades, primarily to prevent moisture migration. They are known to provide a high glossy and shining surface and mostly used on apples, citrus fruits, cucumbers, carrot, sweet potatoes to name a few (Hagenmaier, 2000; Alleyne and Hagenamier, 2000; Fallik et al., 2005).

3.2.1.3 Protein based coatings

Protein- based coatings have been reported to be excellent barriers to oxygen, carbon dioxide and lipids, but have poor water barrier property (Baldwin and Baker, 2002; Kester and Fennema, 1986). These films and coatings are brittle and prone to cracking and hence plasticizers are added to improve film expansibility and viscoelasticity (Sothornvit and Krochta, 2001). Some of the proteins that are widely used in coating formulations for fruits and vegetables include soy protein,
whey protein, casein, corn-zein, egg albumin, collagen and wheat (Baldwin and Baker, 2002).

3.2.1.4 Composite Coatings

In recent times, interest is being shifted towards improvement of film functionality through development of composite or bilayer coatings. These coatings are produced by integration of proteins, polysaccharides, and/or lipids, such that the limitation of each individual coating could be supported by the other coating, and together the functionality of the developed film or coating could be improved.

Composite coatings can be created by the subsequent deposition of different layers (multilayered coatings) or can be made by the deposition of a single layer of material (stable emulsion). Bilayer coatings are formed in two stages. In the first stage the layer of polysaccharide or protein is coated and dried and in the second one, the lipid layer is applied (Krochta, 2002).

3.2.2 Edible coating technology

In order to better understand the coating adhesion and performance characteristics, knowledge about the surface properties of the coating solution and the commodity to be coated is very essential. Some of the important properties that affect the coating effectiveness are discussed in this section.

3.2.2.1 Thickness/viscosity

Thickness/viscosity of the edible coating is an important criterion as it affects the various properties and shelf life of the coated produce. The thickness of the coating depends upon the physical properties of the coating solution and also the method of application of coating (dipping, spraying etc.). It is important to ensure that the applied coatings do not exceed a critical thickness which could reduce internal O\textsubscript{2} concentration and cause anaerobic fermentation due to excess CO\textsubscript{2} production (Cisneros-Zevallos and Krochta, 2003).
3.2.2.2 Wettability

The balance between the adhesive forces of a liquid on a solid surface and the cohesive forces of the liquid determine the wettability of the solid by the liquid. These adhesive and cohesive forces cause the liquid to spread and shrink over the solid surface, respectively. For effective functioning, the edible coatings must wet and spread uniformly over the fruit/vegetable surface and upon drying form a coating with adequate adhesiveness, cohesiveness and durability (Ebnesajjad, 2012). Since the wetting stage is considered to be the shortest and most significant, use of plasticizers such as water, glycerol, sorbitol are incorporated for increasing coating flexibility and toughness.

3.2.2.3 Surface energy of the commodity

Commodities generally have low to high surface energies. Low surface energy commodities have a tendency to repel rather than attract an adhesive/coating, which in turn prevents coating from sufficiently wetting the surface of the commodity. In order to avoid this, surface active agents (Tween – 0.1 to 0.5%) are generally added to the coating solution (Martinez et al., 2013).

3.2.2.4 Contact angle

Contact angle is defined as the angle made by the intersection of the liquid/solid interface and the liquid/air interface (Tracton, 2005). A high contact angle indicates a low solid surface energy or chemical affinity and thereby a low degree of wetting. On the other hand, a low contact angle indicates a high solid surface energy or chemical affinity indicating high or sometimes complete degree of wetting. Contact angle of chitosan solution on apple, tomato and watermelon is reported to be 87-90°, and only 8.5° for pear fruits (Park, 2002).
3.2.3 Aloe gel as edible coating for whole fruits and vegetables

Tropical fruits

In a study on mangoes coated with freeze dried Aloe vera gel (1:1 and 100%), the coatings were reported to delay ripening but caused adverse effects in biosynthesis of sesquiterpenes, monoterpenes, lactones, and aromatic compounds. The authors attributed this to the high concentration of Aloe gel used (Dang et al., 2008).

The effect of Aloe vera gel (1:1) coating for extending the shelf life of papaya was carried out in our laboratory along with other coating materials (Marpudi et al., 2011) i.e. papaya leaf extract incorporated Aloe vera gel (PLEAG) and 2.5% chitosan (CH), and stored at 30±3°C and 40-55% RH. The coatings were found to significantly delay the physiological loss in weight (PLW), ripening process, colour development, softening and decay, exhibit minimal changes in chemical parameters like total soluble solids and acidity and demonstrated improved marketability compared to control fruits.

The effect of Aloe vera gel (1:1) coating was also studied in our laboratory to extend the shelf life of fig fruits stored at room temperature (Marpudi et al., 2013) with positive results. The Aloe gel coated fruits were found to have lower degree of weight loss (PLW) and browning and shriveling of skin, recorded minimal changes in acidity and TSS and minimized fruit decay thereby improving the shelf life and marketability.

Temperate fruits

The earliest scientific report using Aloe vera gel in temperate fruit was carried out on table grapes (Valverde et al., 2005). Table grapes treated with Aloe vera gel were found to have significantly less weight loss, color changes, softening, ripening, rachis browning and decay, compared to control grapes. Aloe gel coating extended shelf life up to 35 days, as against 1 week for control grapes, at 1°C, with better microbial and sensory quality.
In another study conducted by the same group under similar storage condition, table grapes coated with *Aloe vera* gel were reported to significantly delay the unfavorable changes such as rapid loss of functional compounds, reduction of total antioxidant activity and accelerated ripening, thereby retaining the functional aspects of grapes during postharvest storage (Serrano et al., 2006).

The beneficial effect of *Aloe vera* gel coating on sweet cherry quality has been demonstrated (Martinez-Romero et al., 2006). The authors reported *Aloe vera* gel coating to be effective in reducing weight loss, colour changes, softening, ripening, skin browning and in maintaining high microbial quality and sensory acceptability upon cold storage at 1°C.

Nectarine fruits coated with *Aloe vera* gel and stored at ambient or 3 and 6 weeks cold storage were reported to have reduced respiration rate, ethylene production, retarded fruit softening, and reduced electrolyte leakage and weight loss, thereby extending the shelf life of the coated fruits (Ahmed et al., 2009).

In a study on strawberry fruits, the fruits coated with *Aloe vera* gel (1: 3 ratio) were reported to have significantly lower weight loss, better maintenance of colour, firmness, and quality characteristics (total soluble solids, titrable acidity and ascorbic acid) compared to untreated fruits. The authors found the coated fruits to have an extended shelf life of 16 days when stored at 5°C and 95% RH (Singh et al., 2011).

Ravanafar et al., (2012) reported the beneficial effect of *Aloe vera* gel coating and hot water on sour cherry stored for 17 days at 4±1 °C. The researchers reported a significant delay in unfavorable changes in fruit quality such as increased respiration rate, rapid weight loss and colour change, accelerated aging and ripening. The authors also reported the favorable effects of coating on sensory characteristics in terms of delayed dehydration and better maintenance of fruit visual aspect without any detrimental effect on taste, aroma or flavor.

Apples coated with *Aloe vera* gel at 5 and 10% level and stored for 6 months at 2°C were found to retain better quality characteristics like suppressing weight loss,
delaying the reduction of soluble solids and titrable acidity, and impeding change of appearance, compared to control fruits (Ergun and Satici, 2012).

In a recent study, A. vera gel (30% w/w), gum tragacanth (10% w/w) and A. vera – gum tragacanth (20% w/w) (Mohebbi et al., 2012) were reported to be effective physical barriers thereby lowering weight loss, retarding respiration rate and delaying adverse changes in colour, softening and shrinkage in bell pepper fruits stored at different temperatures.

In another study, mushrooms were coated with prepared Aloe vera gel solution/AG (1:3), gum tragacanth solution/GT (1:10) and AG–gum tragacanth combined solution (1:1) (Mohebbi et al., 2012). The AG-gum tragacanth coating was reported to be most effective in minimizing weight loss, colour changes and softening of mushrooms during storage at all temperatures.

In a recent study by Guillen et al., (2013) Aloe arborescens and Aloe vera gel coatings were reported to be effective in delaying ethylene production, reducing acidity and thereby delaying the ripening process in peach and plum fruits. In another recent study (Arowora, 2013) oranges were coated with Aloe vera gel and stored under refrigeration for 8 weeks. Periodic physicochemical analysis of the fruits revealed AG coated fruits to retard weight loss and cause better retention of firmness and vitamin C, along with minimal changes in other parameters thereby retaining the fresh quality of oranges up to 8 weeks.

3.2.4 Chitosan coating applications for fresh fruits and vegetables

Chitosan has been widely used as a coating material for a variety of whole fruits and vegetables. Some of these studies are reviewed below:

El Ghaouth et al., (1991), studied the effect of chitosan coating (1.0 and 1.5% w/v) on the storability of bell pepper and cucumber stored at 13 and 20°C at 85% RH. They found that chitosan coating markedly reduced the weight loss, respiration rate, loss of color, wilting and fungal infection, and thereby extending shelf life.
In a study on Jonagold apples (Du et al., 1998), chitosan treatment at 1% and 1.2% levels extended the shelf life of apples by suppressing ethylene production, respiration rate and by inhibiting conidial germination and fungal decay.

Jiang and Li, (2001) studied the effect of chitosan coating on the postharvest life and quality of longan fruit stored at 2°C and 90% RH. The chitosan treated longan fruits had reduced firmness loss, better retention of vitamin C, reduction in titrable acidity, total soluble solids, decay, respiration rate and polyphenolase activity compared to control fruits.

In a study by Jiang et al., (2005), 2% chitosan coating on litchi fruits stored for 21d at 21°C was effective in delaying decrease in anthocyanin content and increase in polyphenol oxidase activity, minimizing changes in color and eating quality, reduced changes in other physico chemical parameters and extended the shelf life by inhibiting decay.

A study compared different polysaccharide based coatings such as starch, carrageenan and chitosan, with addition of 1% calcium chloride, to extend the shelf life of strawberries. The fruits, coated with 1% chitosan and calcium chloride, were found to exhibit minimum weight loss and microbial growth (Ribeiro et al., 2007).

Xu et al., (2007) studied the effectiveness of grape fruit seed extract and chitosan to control postharvest decay and maintain quality of Red globe grape berries stored at 0-1°C. They found that these treatments alone or in combination efficiently inhibited the fungal rot and maintained its keeping quality.

Indian jujube fruits treated with 1-MCP followed by treatment with 1.5% chitosan were reported to exhibit better chlorophyll retention, ascorbic acid and firmness, delayed ethylene production and respiration rate, thereby extending the shelf life of the fruits stored at room temperature (Qiuping and Wenshui, 2007).

Hernandez-Munoz et al., (2008) studied the effect of chitosan coating combined with postharvest calcium treatment on strawberry quality during refrigerated storage. Strawberries coated with 1%, 1.5% chitosan or chitosan combined with calcium
gluconate (CaGlu) and stored at 10°C at 70±5% RH for one week exhibited delayed changes in weight loss, firmness and external color compared to untreated sample.

Chitosan coating alone (0.75%) and in combination with calcium infiltration (2.5%) was investigated in papaya of mature green stage. Chitosan coating alone was reported to reduce weight loss, delayed color change and changes in other quality aspects. Better results were obtained with calcium infiltration wherein better retention of fruit firmness and extension of storage life to 35 days could be achieved compared to the untreated fruits (Eryani et al., 2008). Another study on papaya stored under cold condition reported treatment with chitosan (1-2% concentration) to be effective in reducing weight loss, maintaining firmness, delaying changes in peel color and other physico chemical parameters and better sensory quality, compared to the untreated fruits (Ali et al., 2011).

A study by Chailoo and Asghari (2011), investigated the effectiveness of 0.5 and 1% chitosan coating, and hot water treatment alone, or in combination in sweet cherries stored in cold storage and 98% RH. The combination treatment was reported to be the best in controlling decay in the fruits, compared to other treatments.

3.3 Materials and methods

3.3.1 Experimental materials – Tomato and fig

The local seeded variety of tomato fruits were procured from the Anantapur market. They were selected in color break stage as per the USDA standard tomato colour classification chart (USDA, 1991). This variety was selected as it is prone to huge postharvest losses compared to the hybrid varieties, and as per the information given by the local farmers and horticultural department. Unripe fig fruits (Poona cultivar) were procured from the marketplace of Anantapur town, India. The fruits having uniform size, appearance, ripeness and those free from defects and physical injuries were selected.
3.3.2 Edible coating solutions

The effect of Aloe gel coating on whole tomato and fig fruits was investigated in comparison to chitosan, an established biopolymer coating substance. Effect of two forms of the selected biopolymers - one prepared in the laboratory and the other obtained commercially was evaluated. The coating solutions used are described below:

- **PAG**: Processed Aloe gel prepared without additives and extensive processing.

  Fresh *Aloe vera* leaves were harvested from the University garden. Healthy leaves free from external damages were chosen. Immediately after harvesting, the top and edges of the leaf were cut. The leaves were placed upright for 30 minutes for draining out the sap/latex. This was followed by removal of the top rind. The clear, transparent mucilage i.e. the *Aloe vera* inner gel fillets were scraped out. The fillets were blended in a mixer, strained to remove the froth and particulates to obtain uniform consistency. The resultant coating solution was stored in a brown bottle under refrigerated conditions, until used (Plate II).

- **CAG**: Commercially sold *Aloe vera* gel (Excel Industries, India); Diluted 3 times with water,

- **PCH**: Purified chitosan prepared in the laboratory (section 2.3.1) from crude chitosan flakes (Panvo Organics, Chennai, India); 2% dissolved in 0.5% aqueous acetic acid solution,

- **CCH**: Commercial grade chitosan (SRL Chemicals); 2% in 0.5% aqueous acetic acid solution.

The developed coating solutions were tested for viscosity using Bostwick consistometer (ZXCON-CON1, Endecotts Limited, England) and the viscosity expressed to the nearest cm. The solutions were tested to ensure similar viscosity range in the coating solutions compared, since viscosity is known to affect the coating ability of the solution. The viscosity of PAG, CAG, PCH and CCH coating solutions obtained was 10.6cm, 10.8cm, 10.5cm and 10.6cm for, respectively.
3.3.3 Application of coating solutions

The selected fruits were divided into five groups, each assigned to a separate coating treatment. They were coated with PAG, CAG, PCH and CCH coating solutions by dipping for one minute. The tomato fruits were designated as TPAG, TCAG, TPCH and TCCH, respectively, and fig fruits as FPAG, FCAG, FPCH and FCCH, respectively. One set was dipped in distilled water which served as control, designated as TC for tomato and FC for fig fruits (Fig 3.1).

3.3.4 Packaging and storage

After the respective coating treatments, the fruits were air dried for about 30 minutes at 25°C. The coated dried fruits (35-40 per treatment) were then stored at 10°C and 85% relative humidity.

The storage temperature of 10°C was selected as this is the recommended temperature especially for unripe tomatoes. Temperatures lower than 10°C has been reported to cause greater chilling injury (Suslow and Cantwell, 2002), especially when stored for a longer period. Also this is the general temperature used in the cooling chambers present in retail outlets.

Figs stored at 10°C and 85% RH have been reported to have a longer shelf life than figs stored at lower temperatures of 4-6°C and room temperature (Ahmed et al., 2012).
Selection of tomato and fig fruits

Tomato

Figs

Coated with various solutions
- Control (C) – Coated with distilled water
- Processed Aloe gel (PAG)
- Commercial Aloe gel (CAG)
- Purified chitosan (PCH)
- Commercial chitosan (CCH)

Coated samples designated as TC, TPAG, TCAG, TPCH and TCCH, respectively

Samples analyzed on 0d, 7d, 14d, 21d and 28d of storage followed by 1 week market simulation study

Coated samples designated as FC, FPAG, FCAG, FPCH and FCCH, respectively

Samples analyzed on 0d, 5d, 10d, 15d, 20d and 25d of storage followed by 1 week market simulation study
3.3.5 Analysis of coated whole fruits

The control and coated fruits were analyzed for various quality parameters namely physiological loss in weight (PLW), titrable acidity (TA), total soluble solids (TSS), firmness, colour, respiration rate, percent decay and sensory acceptability. The analysis was carried out 0d, 7d, 14d, 21d and 28d followed by 1 week of market simulation study for tomato fruits. For figs, the analysis was carried out on 0d, 5d, 10d, 15d, 20d and 25d followed by 1 week of market simulation (MS) study.

3.5.1.1 Physiological loss in weight (PLW)

The PLW was determined by accurately weighing the samples (10 fruits per replication) on the initial day and at the end of each storage interval. The results were expressed as percentage of initial weight.

3.5.1.2 Titrable acidity (TA) and total soluble solids (TSS)

For the determination of TA and TSS, samples from each treatment were ground in a blender and the juice extracted. TSS was determined using a digital refractometer (Atago, Japan) which was standardized with distilled water. Titrable acidity was determined as per the potentiometric titration method given by Ranganna (1986) using 0.1N NaOH and expressed as percentage citric acid.

3.3.5.3 Fruit firmness

Fruit firmness was measured at two points on the shoulder of the fruits (n=5) for each coating treatment. A plunger of 2mm diameter was applied using a digital texture analyzer (Model 53205, Italy make). The amount of force (N) required to compress the radial pericarp of each fruit was recorded.

3.3.5.4 Instrumental color analysis

Instrumental analysis of color of the samples from each treatment was determined using the color reader (Konica-Minolta CR-10) as Hunter L*, a* and b* values. The values were recorded as L* (white 100 to black 0), a* (red 100 to green 0) and b* (yellow 100 to blue 0). The mean L*, a* and b* values were
obtained from 4 points taken along the circumference of each fruit (n=5). The chroma value of the fruits were calculated as per the formula CV = \( (a^2 + b^2)^{0.5} \).

3.3.5.5 Respiration rate

Respiration rate of the samples was analyzed using the closed system method. Weighed fruits (2 per treatment) were placed in a 470 ml PET jar and sealed for 1h at 10°C. A rubber septum was fixed at the centre of the lid of the jar. Gas samples were taken from the jar through a needle inserted through the septum. The needle was connected to CO\(_2\)/O\(_2\) gas analyzer (PBI Dansensor gas analyzer, Checkmate II, Denmark). Results in % CO\(_2\) were used for calculation of respiration rate (mg CO\(_2\)/kg/h) using the following equation

\[
\text{Respiration rate} = \frac{\% \text{ CO}_2}{\text{Mass of sample in Kg} \times \text{seconds incubated}} \times \text{Volume of jar taken}
\]

3.3.5.6 Percentage fruit decay

Percentage fruit decay for the fruits of each treatment was calculated as per the method given by Ali et al., (2011) as per the equation given below

\[
\% \text{ Fruit decay} = \frac{\text{No. of decayed fruits}}{\text{Total number of fruits}} \times 100
\]

3.3.5.7 Marketability

The samples were analyzed for marketability in terms of skin and pulp color, fruit texture, flavor and overall acceptability, by a panel of ten semi-trained female panel members. The panelists were asked to rate the samples on a five point hedonic rating scale wherein 5 indicated excellent marketability and 1 indicated poor marketability. A score below 3 was considered to be the limit of marketability.
3.4 Results and Discussion

The results of the effect of the developed coatings on the shelf life of the selected fruits are presented in this section.

3.4.1 Effect of Aloe gel and chitosan coatings on PLW of tomato and figs

The physiological loss in weight (PLW) is considered to be one of the most critical factors affecting shelf life of the fresh produce. It is mainly associated with respiration of fruits and water evaporation from the fruit surface, which could lead to shriveling and deterioration of quality. The present study demonstrated both the biopolymer coatings to have a beneficial effect on preventing the PLW compared to the uncoated fruits.

Significantly lower PLW was seen in the biopolymer coated tomato and fig samples, compared to uncoated samples till the end of storage period and in the MS conditions (Fig. 3.2). In tomatoes, the control samples TC exhibited maximum loss of 45.6%, significantly higher than all the coated samples i.e. TPAG (13.4), TCAG (26.5), TPCH (18.4) and TCCH (21.4). For figs, control samples FC recorded the highest PLW of 37.8% at the end of 25d storage period and 52.5% at the end of MS study. The other biopolymer coated samples recorded significantly lower PLW with FPAG samples recording the lowest PLW of 15.8%.

Similar results have also been reported in the case of Aloe gel coated fruits such as apples (Ergun and Satici, 2012), sweet cherries (Martinez-Romero et al., 2006) and ‘Arctic snow’ nectarines (Ahmed et al., 2009) and in chitosan coated produce like pears (Lin et al., 2008), cucumber, and bell pepper (El Ghaouth, 1991). The lower PLW in the coated samples could be due to the formation of a water vapor barrier between the fruit surface and the environment, thereby restricting moisture loss from the skin and in turn preventing weight loss.
Fig 3.2 Effect of different biopolymer coatings on the physiological loss in weight (%) of tomato (a) and fig (b) fruits

TC, TPAG, TCAG, TPCH, TCCH – Tomato samples coated with distilled water, PAG, CAG, PCH and CCH, respectively

FC, FPAG, FCAG, FPCH, FCCH – Fig samples coated with distilled water, PAG, CAG, PCH and CCH, respectively
3.4.2 Effect of Aloe gel and chitosan coatings on respiration rate of tomato and figs

The coating of the samples resulted in lowering the respiration rate on the initial day itself. With increase in storage period an increase up to two weeks in uncoated tomato and fig samples, followed by a decrease. The coated tomato and fig samples showed increase up to three weeks, followed by a decrease which continued in the MS period (Fig.3.3).

Both tomato and figs are classified as climacteric fruits (Biale and Young, 1981). In climacteric fruits, the respiration rate increases to a maximum just before full ripening, leading to senescence. A gradual decline in respiratory activity occurs during this post climacteric phase (Sudheer and Indira, 2007). In the present study, the control fruits attained the peak respiration rate earlier than the coated fruits and hence developed early senescence.

In tomato samples at the end of refrigerated storage period, TC sample showed 21.8%, 15.5%, 20.8% and 23.5 % higher RR compared to TPAG, TCAG, TPCH and TCCH samples, respectively. In the case of figs, 19.3%, 7.3%, 16.3% and 17.6% lower RR was recorded by FPAG, FCAG, FPCH AND FCCH, respectively, compared to FC.

At the end of MS, no significant differences were detected between the control and CAG treated samples. However, PAG, PCH and CCH coated fruits recorded significantly lower RR.

A lower RR in the coated fruits could be attributed to the beneficial effects of the biopolymer coatings on the modification of the internal atmosphere of fruits i.e. increase in CO₂ and decrease in O₂, thereby slowing down the respiration rate of the fresh fruits. Similar observations have also been made in other fruits treated with Aloe gel such as sweet cherry (Martínez-Romero et al., 2006) and chitosan coated produce such as pears (Lin et al., 2008), strawberries (El Ghaouth et al., 1991) and peaches (Li and Yu, 2001).
Fig. 3.3 Effect of different biopolymer coatings on the respiration rate (mg CO$_2$/kg/hr) of tomato (a) and fig (b) fruits

TC, TPAG, TCAG, TPCH, TCCH – Tomato samples coated with distilled water, PAG, CAG, PCH and CCH, respectively

FC, FPAG, FCAG, FPCH, FCCH – Fig samples coated with distilled water, PAG, CAG, PCH and CCH, respectively
3.4.3 Effect of Aloe gel and chitosan coatings on chroma value of tomato and figs

An initial chroma value ranging from 30.1-31.8 and 18.6-20.3 was seen in the tomato and fig samples, respectively, on the initial day (Fig.3.4).

An increase in chroma value was witnessed in both tomato and fig samples on storage which could be related to the ripening of the fruits. End of storage period witnessed highest CV in TC (52.5) which further increased to 58.2 in the MS period. In case of figs too, FC sample showed highest CV of 44.3 at the end of 25d storage and 48.5 in the MS study. Significantly lower CV in tomato and fig samples coated with PAG, PCH and CCH could be attributed to the beneficial effect of the biopolymer coatings in delaying ripening by providing a barrier to gas exchange between the fruit and the outer environment. This in turn could have delayed the degradation of chlorophyll and subsequent synthesis of carotenoids, leading to retardation in color development. Commercial Aloe gel coated samples recorded significantly lower CV in both tomato and fig samples.

Similar delayed ripening and corresponding slower color change has also been reported in Aloe gel coated apples (Ergun and Satici, 2012) and chitosan coated strawberries (El Ghaouth et al., 1991).
Fig. 3.4 Effect of different biopolymer coatings on the chroma value of tomato (a) and fig (b) fruits

TC, TPAG, TCAG, TPCH, TCCH – Tomato samples coated with distilled water, PAG, CAG, PCH and CCH, respectively

FC, FPAG, FCAG, FPCH, FCCH – Fig samples coated with distilled water, PAG, CAG, PCH and CCH, respectively
3.4.4 Effect of Aloe gel and chitosan coatings on firmness of tomato and figs

Firmness is a crucial criterion determining the shelf life and marketability of fresh produce. There was a gradual reduction and better maintenance of firmness in biopolymer coated fruits throughout the refrigerated storage period and during MS, compared to control samples (Fig. 3.5). In the uncoated control, the reduction in firmness was sharper and faster, especially during MS. Both for tomato and figs, PAG, PCH and CCH coated samples maintained significantly higher firmness values compared to control and CAG coated samples. Among the biopolymer coatings, PAG coating aided in maintaining highest firmness values. Hence, TPAG samples recorded 60% greater firmness compared to TC, whereas, FPAG samples showed 82% more firmness compared to FC even at the end of MS study.

The higher firmness in the coated samples could be due to the barrier property of the coating materials which prevent loss of water, thereby promoting water retention and turgidity of the fruit tissues. The coatings could also have some effect on retarding the action of cell-wall degrading enzymes which are responsible for tissue softening. Delayed ripening is also another contributing factor for longer maintenance of firmness (No et al., 2007).

Better maintenance of firmness with the biopolymer coating has also been reported in case of Aloe gel coated sweet cherries (Martinez-Romero et al., 2006) and nectarines (Ahmed et al., 2009) and chitosan coated fruits like strawberries, raspberries and others (No et al., 2007).

3.4.5 Effect of Aloe gel and chitosan coatings on titrable acidity and total soluble solids of tomato and figs

The titrable acidity (TA) and total soluble solids (TSS) of the samples are depicted in Fig. 3.6 and 3.7, respectively.
Fig. 3.5 Effect of different biopolymer coatings on the firmness (N) of tomato (a) and fig (b) fruits

TC, TPAG, TCAG, TPCH, TCCH – Tomato samples coated with distilled water, PAG, CAG, PCH and CCH, respectively

FC, FPAG, FCAG, FPCH, FCCH – Fig samples coated with distilled water, PAG, CAG, PCH and CCH, respectively
Fig. 3.6 Effect of different biopolymer coatings on the titrable acidity (%) of tomato (a) and fig (b) fruits

TC, TPAG, TCAG, TPCH, TCCH – Tomato samples coated with distilled water, PAG, CAG, PCH and CCH, respectively

FC, FPAG, FCAG, FPCH, FCCH – Fig samples coated with distilled water, PAG, CAG, PCH and CCH, respectively
Fig. 3.7 Effect of different biopolymer coatings on the total soluble solids (°Brix) of tomato (a) and fig (b) fruits

TC, TPAG, TCAG, TPCH, TCCH – Tomato samples coated with distilled water, PAG, CAG, PCH and CCH, respectively

FC, FPAG, FCAG, FPCH, FCCH – Fig samples coated with distilled water, PAG, CAG, PCH and CCH, respectively
Samples recorded similar titrable acidity on the initial day with the values ranging from 0.42-0.45 for both tomato and fig fruits. A decrease in TA was found in both the coated and uncoated samples on storage, which could be attributed to the natural phenomenon of ripening (Fig. 3.6). At the end of 28d storage period, TA value reduced by 0.1 unit in PAG, PCH and CCH coated tomatoes, whereas, a greater reduction by 0.15 units and 0.2 units was seen in CAG and control fruits, respectively. Overall reduction in TA in fig fruits was greater than tomato. Reduction in TA of coated figs was slightly lower than control. Similar effect of the coatings was observed during MS with PAG and PCH treated tomato and fig fruits showing least reduction in TA.

Initial TSS of tomato and fig coated fruits were found to range from 2.1-2.3 and from 4.1-4.5, respectively. An increase in TSS was observed in all the samples on storage. However, control samples recorded significantly higher TSS throughout the storage period in both tomato and fig samples.

In the MS study, highest TSS was recorded by TC (7.5 °Brix) and FC (13.5 °Brix) followed by CAG coated samples. Least TSS in tomatoes was seen in TPAG (6.1 °Brix). In fig fruits FPCH (8.13 °Brix) and FPAG (8.16 °Brix) showed lowest TSS.

Similar effect on TA and TSS have been reported in Aloe gel coated table grapes (Serrano et al., 2006) and chitosan coated papaya fruits (Eryani et al., 2008).

Reduction in acidity and subsequent increase in TSS is indicative of maturation which was faster and more pronounced in control and CAG coated fruits compared to other coated fruits. Increase in maturity and senescence results in lower shelf life of fresh produce.

**3.4.6 Effect of Aloe gel and chitosan coatings on percent fruit decay in tomato and figs**

Decay started in the TC and FC samples within one week of storage, whereas, the coated tomato and fig samples remained free from decay up to two weeks, with a lower decay-free period of ten days in CAG coated fruits (Fig. 3.8).
Fig. 3.8 Effect of different biopolymer coatings on the fruit decay (%) of tomato (a) and fig (b) fruits

TC, TPAG, TCAG, TPCH, TCCH – Tomato samples coated with distilled water, PAG, CAG, PCH and CCH, respectively

FC, FPAG, FCAG, FPCH, FCCH – Fig samples coated with distilled water, PAG, CAG, PCH and CCH, respectively
End of refrigerated storage was marked by the control samples recording more than 80% decay, whereas the PAG, PCH and CCH coated fruits showed less than 30% decay.

The control samples of both tomato and figs were found to completely decay within 2 days of the MS. On the other hand, the biopolymer coatings helped in controlling the decay to a large extent with the PAG coated samples demonstrating the least decay percentage of 25% and 35% in tomato and figs, respectively, during MS. Significantly lower decay recorded in the biopolymer coated samples could be attributed to the strong antimicrobial activity of Aloe gel against plant pathogens (Jasso de Rodríguez et al., 2005) and chitosan (Goy et al., 2009) biopolymers.

3.4.7 Effect of Aloe gel and chitosan coatings on marketability of tomato and figs

Marketability is an important parameter that relates to the consumer preference and sale of the fresh produce. For tomato fruits marketability was based upon the uniformity of ripening, fruit firmness and minimal shriveling of skin. In case of figs, firmness was seen to be the most important criterion followed by degree of browning and shriveling of skin. For both the fruits, a score of 3 was decided to be the limit of marketability. Initially, higher scores of marketability i.e. above 4.5 were recorded by all the samples. However on storage, the scores reduced mainly due to loss of firmness.

Except CAG coated fruits, other coated samples maintained good marketability even at the end of storage period (28d for tomato and 25d for figs). However, the uncoated tomato and fig fruits showed loss of marketability within three weeks. During MS period also, only PAG, PCH and CCH coated tomato and fig fruits remained marketable.

Overall, it could be concluded that both the chitosan coatings and the prepared Aloe gel coating were very effective in extending the shelf life of the coated fruits. CAG coated fruits recorded a delay in surface color development but could not delay the ripening process as evidenced by the higher TSS content, respiration rate and rapid loss of firmness during storage.
Fig. 3.9 Effect of different biopolymer coatings on the marketability of tomato (a) and fig (b) fruits

TC, TPAG, TCAG, TPCH, TCCH – Tomato samples coated with distilled water, PAG, CAG, PCH and CCH, respectively

FC, FPAG, FCAG, FPCH, FCCH – Fig samples coated with distilled water, PAG, CAG, PCH and CCH, respectively
This could be attributed to the observation that PAG, PCH and CCH coating solutions formed a thin, uniform coating layer on the fruit surface and the excess coating was found to slide down during the drying process. A comparatively thicker coating layer was formed by CAG on the fruit surface due to the excess coating solution remaining on the fruit surface. This could have in turn led to anaerobic respiration as also reported in commercially obtained Aloe gel coated mango (Dang et al., 2004), and thereby led to a reduction in shelf life.

Another important beneficial effect observed in the PAG, PCH and CCH fruits were the uniformity of ripening, unlike the control and CAG coated fruits which showed uneven ripening. This in turn reflects the ability of the coatings to prevent chilling injury, since chilling injury is one of the causes uneven ripening and increased susceptibility to post harvest decay (www.rfcarchives.org.au).

Chilling injury has been reported to cause several detrimental effects such as failure to ripen, uneven ripening, surface pitting, premature softening and greater degree of decay, which are apparent when the fruits are transferred to market conditions (Paull, 1990).

3.5 Conclusions

The present investigation explored the efficacy of Aloe gel and chitosan for shelf life extension of tomatoes and figs. This is probably the first report on the successful application of fresh Aloe gel as an edible coating for shelf life extension of whole tomatoes and figs stored at low temperature, and chitosan coating on figs. Aloe gel was found to perform similar or better than chitosan, an established coating material. The study demonstrates that minimally processed Aloe gel is more preferable and suitable for use as coating in comparison to processed gels available in the market at higher costs. Both the commercial grade and lab processed chitosan products showed similar efficacy as edible coating in the selected fruits. The ease of availability of these biopolymers and comparatively low cost could facilitate their commercial utilization as edible coatings for enhancing the postharvest quality and shelf life of tomatoes and figs.