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Effects of *Opuntia* Cactus Mucilage Extract and Storage under Evaporative Coolant System on the Shelf Life of *Carica papaya* Fruits

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ABSTRACT

The increase in papaya production requires new strategies to extend the storage life of the fruit. Edible coatings act as physical barriers when applied on the surface of fruits and effectively change their internal atmosphere and delay the ripening process. In the present study, two different coatings were developed from the mucilage of *Opuntia* cactus and their effects were investigated on the quality and storability of papaya fruits. The two experimental coatings were pure mucilage extracts (ME) and mucilage extract mixed with 5 mL glycerol (MEG) which served as plasticizer. The parameters measured were weight loss, ascorbic acid content, pH, firmness, total soluble solid and the microbial qualities of papaya fruits. Papaya fruits were stored for six weeks at an average temperature of 27 ± 2 °C and relative humidity of 55-60% under an Evaporative Coolant System (ECS). Prior to storage, the papaya fruits were surface sterilized using 100 mg/L sodium hypochlorite and randomly arranged into three treatments, the control (untreated) and the two coating treatments. After six week of storage the concentration of yeast and mold was found to decrease in the control from 8.89 log CFU/g to 3.87 log CFU/g (MEG) and 4.78 log CFU/g (ME); also the concentration of aerobic psychrotrophic bacteria decreased from 11.22 log CFU/g in the control to 4.21 log CFU/g (MEG) and 6.02 log CFU/g (ME) mucilage treated fruits while the concentration of aerobic mesophilic bacteria was decreased from 9.78 log CFU/g in the control to 4.98 log CFU/g (MEG) and 6.32 log CFU/g (ME) mucilage treated fruits. The above parameters which are related to post-harvest quality loss were however significantly controlled in the coated papaya. The overall result showed that cactus mucilage was effective in extending the shelf-life of papaya fruits when compared to the control. MEG was more effective than ME.

Keywords: *Carica papaya*, edible coating, glycerol, *Opuntia* cactus, Evaporative Coolant System (ECS)

ABSTRAK

Peningkatan dalam pengeluaran betik memerlukan strategi baru untuk melanjutkan jangka hayat penyimpanan buah. Salutan yang boleh dimakan bertindak sebagai sekatan fizikal apabila digunakan pada permukaan buah yang mana ianya berkesan dalam mengubah keadaan dalaman buah betik dan melambatkan proses pematangan. Dalam kajian ini, dua jenis lapisan yang berbeza telah dibangunkan dari lendir kaktus dan kesan mereka terhadap kualiti dan jangka hayat buah betik telah dikaji. Kedua lapisan eksperimen: Ekstrak Lendir Tulen (ELT) dan ekstrak lendir bercampur dengan 5 mL gliserol (ELTG) telah bertindak sebagai agen plastik. Parameter yang diukur ialah penurunan berat buah, kandungan asid askorbik, pH, kekerasan, jumlah pepejal terlarut dan kualiti mikrob buah betik. Buah betik disimpan selama enam minggu pada suhu purata 27 ± 2 °C dan kelembapan relatif 55-60% di bawah Sistem Penyejuk Penyejatan (SPP). Sebelum penyimpanan, permukaan buah betik telah disterilkan dengan menggunakan 100 mg/L natrium hipoklorit dan disusun secara rawak kepada tiga jenis rawatan; kawalan (tidak dirawat) dan dua rawatan salutan. Selepas enam minggu penyimpanan, kepekatan yis dan kulat didapati menurun bagi kawalan dari 8.89 log CFU/g kepada 3.87 log CFU/g (ELTG) dan 4.78 log CFU/g (ELT), secara berurutan, juga kepekatan bakteria aerobik psikrotrofik menurun daripada 11.22 log CFU/g (kawalan) kepada 4.21 log CFU/g (ELTG) dan 6.02 log CFU/g (ELT), manakala kepekatan bakteria aerobik mesofilik turut menurun daripada 9.78 log CFU/g (kawalan) kepada 4.98 log CFU/g (ELTG) dan 6.32 log CFU/g (ELT). Parameter-parameter di atas yang berkaitan dengan pengurangan kualiti lepas tuai bagaimanapun telah dikawal dengan ketara dalam betik yang bersalut. Keputusan keseluruhan menunjukkan bahawa lendir kaktus adalah berkesan dalam melanjutkan jangka hayat buah betik berbanding dengan kawalan. ELTG didapati lebih berkesan daripada ELT.

Kata kunci: *Carica papaya*, salutan yang boleh dimakan, gliserol, kaktus *Opunti*a, Sistem Penyejuk Penyejatan (SPP)

INTRODUCTION

Carica papaya L. (Family: Caricaceae) is a herbaceous plant with a soft stem, which may grow as high as 8 m. It produces male, female, and bisexual flowers. The male plants do not normally produce fruits. It is a cross-pollinated plant widely grown in the tropics and subtropics. Over 6.8 million tonnes (Mt) of fruit were produced in 2004 in about 389,990 ha. Of this total volume, 47% is produced in Central and South America (mainly in Brazil), 30% in Asia, and 20% in Africa (FAO, 2007). Approximately 30-100% of the fruits and vegetables are being wasted in Nigeria (Oluwalana, 2006). Nigeria continues to be the third largest producer of papaya globally, and its level of production has been estimated to be 765,000 metric tonnes (FAO, 2007).

Papaya fruit is a rich source of nutrients such as acarotenoids provitamin, C and B vitamins, lycopene, dietary minerals and dietary fiber. Papaya skin, pulp and seeds also contain a variety of phytochemicals (Echeverri *et al.,* 1997). Edible films and coatings are environmental-friendly alternative methods, to extend the postharvest life of fresh and minimally processed fruits and vegetables (Baldwin, 1994; Pérez-Gago *et al.*, 2005; Olivas *et al.*, 2008; Vargas *et al.*, 2008). These coatings form a semi-permeable barrier to gases and water vapor that reduce respiration and weight loss of fruits. In addition, edible films and coatings may help to maintain firmness and provide a glossy appearance of coated fruits (Reinoso *et al.*, 2008).

According to their components, edible films and coatings can be divided into three categories: Hydrocolloids (proteins and polysaccharides), lipids and composites. Further, antioxidants, flavors and pigments, vitamins and antimicrobial agents can be successfully incorporated into edible coatings to improve their functional properties. Several reviews have reported the efficacy of films and coatings containing antimicrobials to control microbial growth on fruits and vegetables (Cagri *et al.*, 2004; Ayala-Zavala *et al.*, 2008).

Cactus mucilage may find applications in food, cosmetics, pharmaceutical and other industries. This complex polysaccharide is part of a dietary fiber and has the capacity to absorb large amounts of water, dissolving and dispersing itself and forming viscous or gelatinous colloids (Dominguez-López, 1995).

It has been reported that the addition of a small amount of other edible materials and additives such as lipids, proteins, emulsifiers and plasticizers (glycerol and sorbitol) can improve the performance of polysaccharide based edible coatings in order to delay the ripening of tropical fruits (Olivas and Barbosa-Canovas, 2005). Glycerol is a plasticizer and is included in the edible coating formulations to modify the mechanical properties and produce more flexible coatings (Olivas and Barbosa-Canovas, 2005).

The objective of the study was to investigate the suitability of prickly pear cactus (*Opuntia ficus-indica* (L.) Mill.) mucilage as an edible coating to extend the shelf-life of papaya fruits.

MATERIALS AND METHODS

Preparation of Coating Solution

Cactus stems were peeled and cubed (1 cm^3). Samples were homogenized (20% w/v) in distilled water. The slurry was centrifuged for 10 minutes at 4,500 rpm and the supernatant obtained was used to prepare the edible coating (Sáenz *et al.*, 1992). It was then pasteurized at 70 ^oC for 45 minutes to form a pure mucilage extract (ME). Papaya were dipped in coating solution for 30 seconds, the excess coating was drained and the coated papaya were dried in a forced-air dryer (20 ^oC) for 30 minutes. Papaya dipped in distilled water were used as a blank.

Treatments

There were three treatments employed, namely T_0 (control): Untreated papaya; $T_{1:}$ Papaya coated with pure mucilage extract (ME) and T2: Papaya coated with mucilage extract mixed with 5 mL glycerol (MEG). The treated and untreated fruits were packed in plastic baskets of 60 cm width by 30 cm height and each basket contained six papaya fruits per treatment. The baskets were stored at ECS temperature and relative humidity (27 ± 2 °C and 55-60%).

Source of Papaya

Freshly harvested papayas were procured from a local market in Ilorin, Kwara state, Nigeria. Mature unripe papayas were selected on the basis of size, green color and absence of external injuries. They had an approximate weight of 0.45 kg each.

The Evaporative Cooling System (ECS)

The evaporative cooler (800 cm × 300 cm) used for this study consisted of a double-walled rectangular brick construction with the inter-space filled with riverbed sand saturated with water. The clay bricks used in the wall construction were factory baked at 600 ^oC and had the dimension of 25.5 cm × 12.0 cm × 6 cm. The interior surfaces of the cooling chamber walls were given a smooth finish with 1.2 cm thick cement plaster, while a heat insulating cover of 1.9 cm thick particle board closed the top. The walls were built on a short plinth of concrete to prevent water seepage into the soil. Two framed doors (60 cm × 30 cm) of sawn wood were fixed one to each of the adjacent walls on the side to provide access to the 1.38 m^3 capacity chamber. The two doors were considered adequate for thermal insulation against heat flux. This structure was erected in an open space exposed to free air; however it was shaded from direct solar radiation with an open-sided shed of thatch.

Physico-chemical Analyses of Fruits

The following analyses were carried out between 1 to 6 weeks after coating.

Weight loss

The same sample replicates (three) of each treatment were evaluated for weight losses at weekly intervals until the end of experiment. Weight loss was determined by the following formula:

$$\text{Weight loss } (\%) = [(A-B)/A] \times 100$$

where,

A indicates the fruit weight at the time of harvest, and
B indicates the fruit weight after storage intervals (A.O.A.C., 1994).

Firmness

Firmness was measured as the maximum penetration force (N) reached during tissue breakage, and was determined with a 5 mm diameter flat probe. The penetration depth was 5 mm and the cross-head speed was 5 mm/s by using a TA-XT2 Texture Analyzer (Stable Micro Systems, Godalming, U.K). Papayas were sliced into halves and each half was measured in the central zone (Adetunji *et al.*, 2012).

pH

After firmness analysis, papaya were cut into small pieces and homogenized in a grinder, and 10 g of ground papaya was suspended in 100 mL of distilled water and subsequently filtered. The pH of the filtrate from the papaya was assessed using a pH meter (Model pH-526; WTW Measurement Systems, Wissenschaftlich, TechnischeWerkstätten GmBH, Wellhelm, Germany) (A.O.A.C., 1994).

Ascorbic acid

Ascorbic acid content was measured by using 2, 5-6 dicholorophenol indophenol method (A.O.A.C., 1994).

Total soluble solids

Total soluble solids (TSS) were measured by the method described by Dong *et al.,* (2001). Sliced portion of papaya of 5 g from each of the treatments was ground in an Electric Juice Extractor (Model BJE200XL, Breville Juice Fountain Compact

Juicer, U.S.A.). The resulting freshly prepared juice was used to measure soluble solids content using portable hand refractometer in BRIX% (Model 10430 Porx-reading 0.30 ranges, Bausch and Lomb Co., California, U.S.A.) (Adetunji *et al.*, 2012).

Microbial Analysis

Approximately 5 g of papaya fruit pulp was removed aseptically from each treatment. The sample was then homogenized in peptone saline solution (8.5 g/L NaCl + 1 g/L peptone for 1 minute in a Stomacher (Model S400, Shanghai Scientific Instrument Co. Ltd., Shanghai, China). After making serial dilutions in peptone water, the samples were plated on different media as follows: (1) plate count agar (PCA) for isolating total aerobic psychrotrophic micro-organisms was incubated at 12 ^{o}C for 72 hours and mesophilic micro-organisms was incubated at 30 ^{o}C for 72 hours; (2) Sabouraud media (Oxoid CM41) for isolating yeasts and molds was incubated at 25 ^{o}C for 120 hours. Colonies were counted and the results were expressed as CFU/g of papaya. Analyses were carried out periodically by randomly sampled from the baskets.

Statistics

All results were expressed as means ± S.E. The SPSS software (version 12.0, SPSS Inc., USA) was used for all statistical analysis. The significance level used was 0.05.

RESULTS AND DISCUSSION

Firmness (N)

The effects of mucilage coatings on firmness of papaya fruits stored in ECS are shown in Figure 1. The mean ± S.E. values for the firmness of coated MEG and ME papaya were 384.89 ± 63.99 N and 353.75 ± 70.97 N, respectively, while the mean ± S.E. firmness of uncoated papaya was 294.82 ± 73.38 N.

These results were in agreement with those of El Ghaouth *et al.* (1991a, b) where retention of flesh firmness of strawberries had been achieved by a chitosan coating. Diab *et al.* (2001) also showed a delayed loss of firmness in this fruit by applying apullulan-based edible coating. During storage, the texture of the fruits is likely to soften due to several factors such as loss in cell turgidity pressure, loss of extracellular and vascular air and the degradation of the cell wall and consequent loss of water by the cell breakdown (Somogyi *et al.*, 1996; Martínez-Ferrer *et al.,* 2002). Despite the hydrophilic character of polysaccharides, they can act as a barrier to water transfer, retarding dehydration and, therefore, prolonging the firmness of the coated fruit. Addition of glycerol at 5% to the coating solution had no significant effect on the firmness of coated papaya. Glycerol was added to increase the flexibility of the coating and hence avoided splitting on the coated fruit. Cracking of the coating lacking in glycerol was also not observed since water itself acted as a plasticizer, due to the high water activity of papaya.

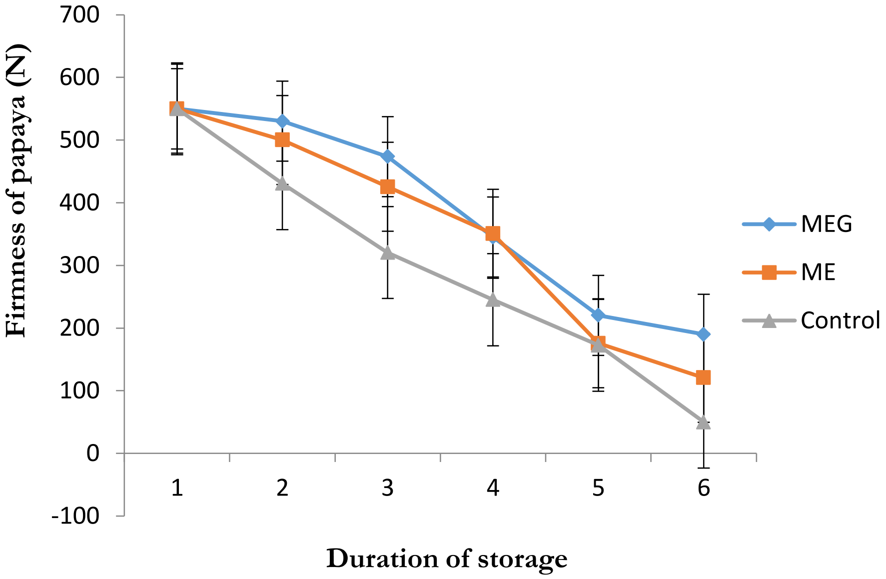

Fig. 1: Effect of *Opuntia* cactus mucilage on firmness (N) of papaya during storage in ECS.

pH

The pH of papaya fruit gradually increased during storage. The mean ± S.E. value of pH of coated MEG and ME were 6.15 ± 0.07 and 6.11 ± 0.06, respectively, while the mean ± S.E. of uncoated papaya was 5.96 ± 0.01 after six weeks of storage.

The pH increased significantly ($p<0.05$) with increased storage time in both coated and uncoated fruits (Fig. 2). These results are in agreement with those reported by El-Ghaouth *et al.* (1991a, b) and Garcia *et al.* (1998). The decrease of acidity during storage demonstrated fruit senescence. The change in pH can be associated with a number of reasons such as effect of treatment on the biochemical condition of the fruit, and slower rate of respiration and metabolic activity (Jitareerat *et al.*, 2007).

Coatings applied effectively delayed fruit senescence. This could probably be due to the semi-permeable chitosan film formed on the surface of the fruit, which may have modified the internal atmosphere *i.e.,* endogenous CO_2 and O_2 concentrations of the fruit, thus retarding ripening (Lowings and Cutts, 1982; Bai *et al.*, 1988). The increase in pH may be due to the breakup of acids along respiration during storage (Pesis *et al.,* 1999).

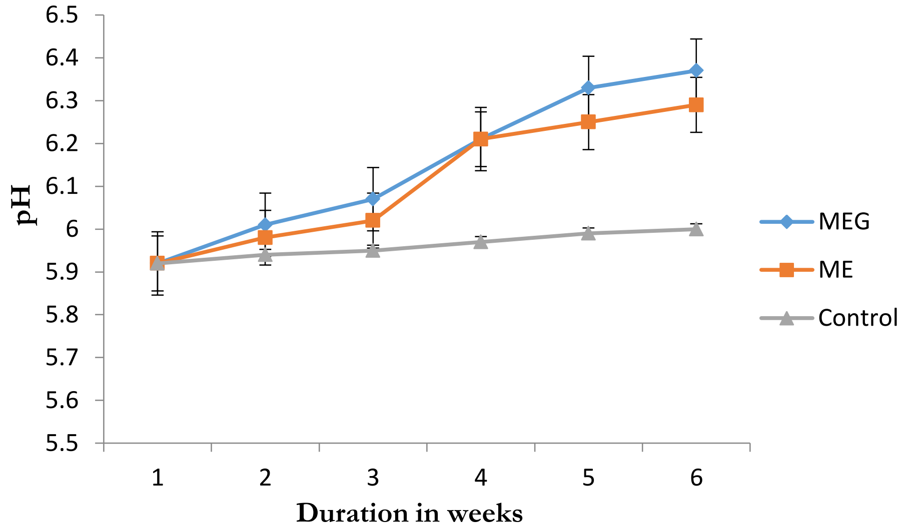

Fig. 2: Effect of *Opuntia* cactus mucilage on pH of papaya during storage in ECS.

Ascorbic Acid

The mean ± S.E. value for the coated MEG and ME of vitamin C were 6.00 ± 0.93 mg/100 g and 5.68 ± 1.01 mg/100 g, respectively, for coated papaya while the mean ± S.E. value for vitamin C for uncoated papaya was 3.96 ± 1.27 mg/100 g.

The results illustrated in Figure 3 revealed that there was a significant decrease in ascorbic acid values of *Opuntia* cactus mucilage-coated fruits along with the storage period. However, the rate of decrease in vitamin C was significantly higher in untreated control fruits as compared with coated fruits. The present study showed that vitamin C was mostly high in mature but unripe papaya fruits, and it decreased as the ripening progressed.

The reason for high vitamin C content in coated fruit can be attributed to slow ripening rate of chitosan-treated fruit. Oxidation of ascorbic acid may be caused by several factors including exposure to oxygen, metals, light, heat and alkaline pH (Sritananan *et al.*, 2005). Coatings served as a protective layer and control the permeability of O_2 and CO_2 (Srinivasa *et al.*, 2002). The results are in agreement with the findings of Jiang *et al.* (2004) who reported that ascorbic acid content decreased when *Longan* fruit was coated with chitosan at a low temperature of 2 °C.

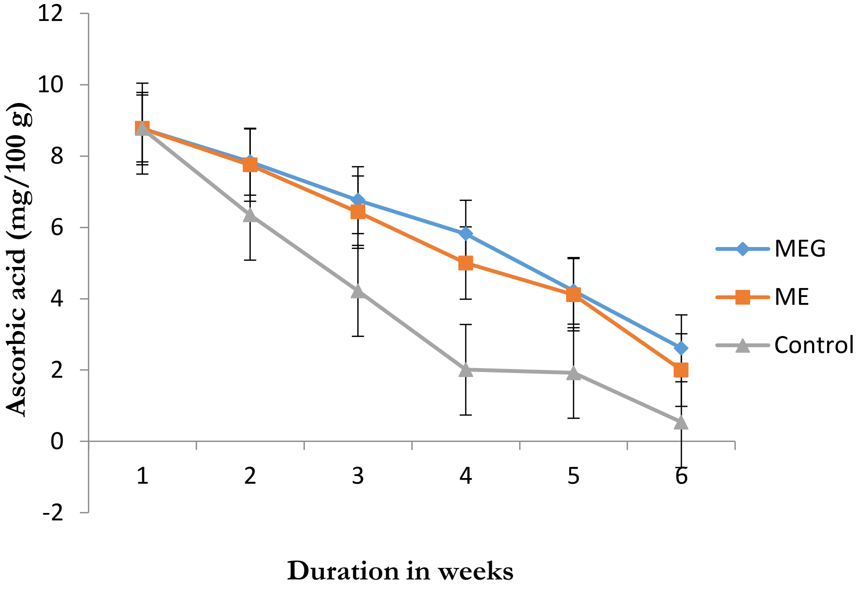

Fig. 3: Effect of *Opuntia* cactus mucilage on ascorbic acid (mg/100 g) of papaya during storage in ECS

Percentage Weight Loss

The coated fruits (MEG and ME) showed a decrease ($p<0.05$) in weight loss compared with the control sample. The mean ± S.E. value for the weight loss of MEG and ME were 3.36 ± 0.01 g and 3.40 ± 0.02 g, respectively, while the mean ± S.E. value for the weight loss of uncoated papaya was 3.46 ± 0.04 g.

Weight loss is an important index of storage life in fresh produce. It is mainly attributed to the loss of water during metabolic processes like respiration and transpiration. Moisture loss and gaseous exchange from the fruits is usually controlled by the epidermal layers provided with guard cells and stomata. The coating helps to reduce this further since it forms a film on the top of the skin acting as an additional barrier to moisture loss (Togrul and Arslan, 2004). These barriers also reduce the oxygen uptake by the fruit which in turn slows down the rate of respiration and associated weight loss from the fruit surface. On the other hand, respiration causes a weight reduction because a carbon atom is lost from the fruit in each cycle (Labuza, 1984; Pan and Bhowmilk, 1992).

However, the coating process caused a decrease in weight loss with *Opuntia* cactus mucilage compared to the control sample. This reduction in weight loss was probably due to the effects of these coatings as a semi permeable barrier against oxygen, carbon dioxide, moisture and solute movement, thereby reducing respiration, water loss and oxidation reaction rates (Baldwin *et al.*, 1999; Park, 1999).

The results of this investigation were in good agreement with the findings by García *et al.* (1998a, b) for strawberries coated with starch-based coatings and those of Joyce *et al.* (1995), who reported that waxing extended the storage life of avocado both through a reduction in water loss and a modification of the internal atmosphere.

Similar data were reported by Bai *et al.* (2003) studying the *Gala* apples coated with 10% zein (a natural corn protein). Sumnu and Bayindirli (1995) noted that *Semperfresh* (10 g/L), *Jonfresh* and *Fomesa* apple wax coatings are efficient in reducing the rate weight loss of *Amasya* apples. Chitosan and polyethylene wax (PE) coatings also provide good protection for *Hami* melon (Cong *et al.*, 2007).

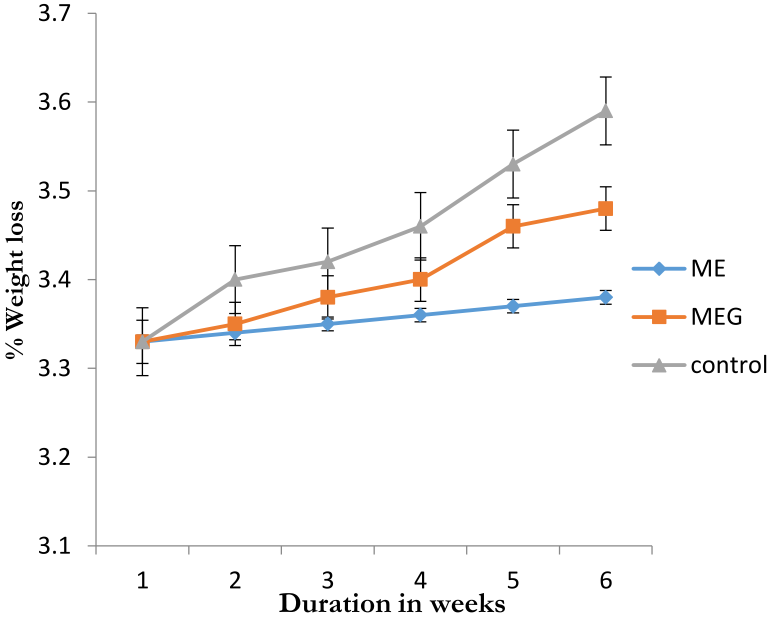

Fig. 4: Effect of *Opuntia* cactus mucilage on percentage weight loss of papaya during storage in ECS

Total Soluble Solids (TSS)

The mean ± S.E. value for the TSS coatings from MEG and ME on papaya were 7.42 ± 0.31 degree BRIX and 9.25 ± 0.34 degree BRIX, respectively, while the mean ± S.E. value for the uncoated fruit was 9.66 ± 0.49 degree BRIX.

These results were in agreement with those of Smith and Stow (1984) who concluded that coatings and/or films significantly affected TSS. Soluble solids content of coated and uncoated papaya stored under ECS condition decreased at the end of the storage period.

The loss of soluble solids during the storage period is natural, as sugars which are the primary constituent of the soluble solids content of a product, are consumed by respiration and used for the metabolic activities of the fruits (Özden and Bayindirli, 2002).

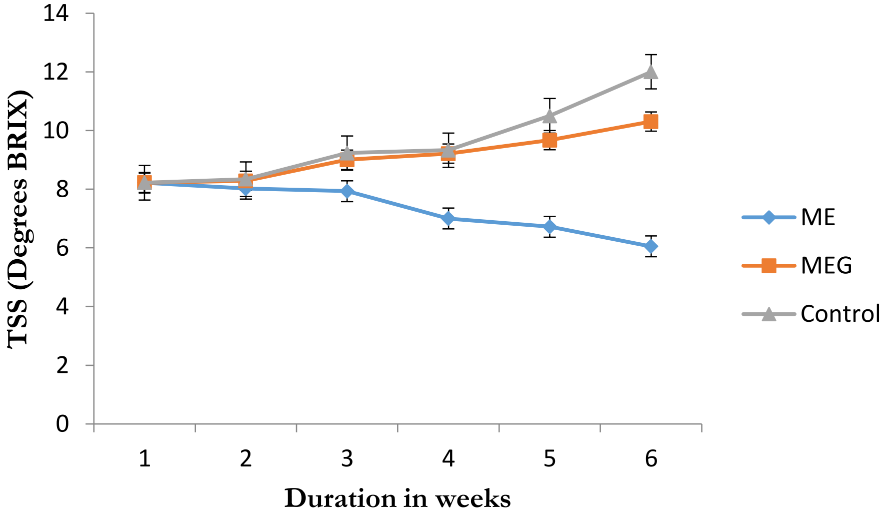

Fig. 5: Effect of *Opuntia* cactus mucilage on TSS (degrees BRIX) of papaya during storage in ECS.

Yeast and Mold Counts

Changes in the total number of yeasts and molds in papaya stored for six weeks at of 27 ± 2 °C and relative humidity of 55-60% are shown in Figure 6. The initial yeasts and molds load in control samples from MEG and ME were 1.23 and 1.32 log CFU/g, respectively, in the first week while that of the control was 1.78 log CFU/g. The mean ± S.E. values for yeast and molds counts of coatings from

MEG and ME on papaya were 2.50 ± 0.58 and 3.15 ± 0.59 log CFU/g, respectively, while the mean ± S.E. value for the uncoated was 4.63 ± 1.15 log CFU/g. During the period of storage coating hindered the increase in aerobic yeasts and molds count compared with the control samples (Fig. 6). At the end of the storage period the coated papaya with MEG and ME were able to hinder the growth of microorganisms resulting in lower microbial loads of 3.87 and 4.78 log CFU/g, respectively, while the uncoated fruit had a higher microbial load of 8.89 log CFU/g. These results were in agreement with those found by other authors who used other types of edible coatings. Lee *et al.* (2003) reported very similar results for minimally processed apples with various types of carbohydrate polymers and whey protein concentrate, using ascorbic acid, citric acid and oxalic acid as anti-browning agents. Howard and Dewi (1995) used an edible cellulose-based coating on mini-peeled carrots and investigated microbial quality during storage at 21 °C. As stated by Olivas and Barbosa-Cánovas (2005), coatings create a modified atmosphere that may change the growth rate of spoilage and pathogenic microorganisms.

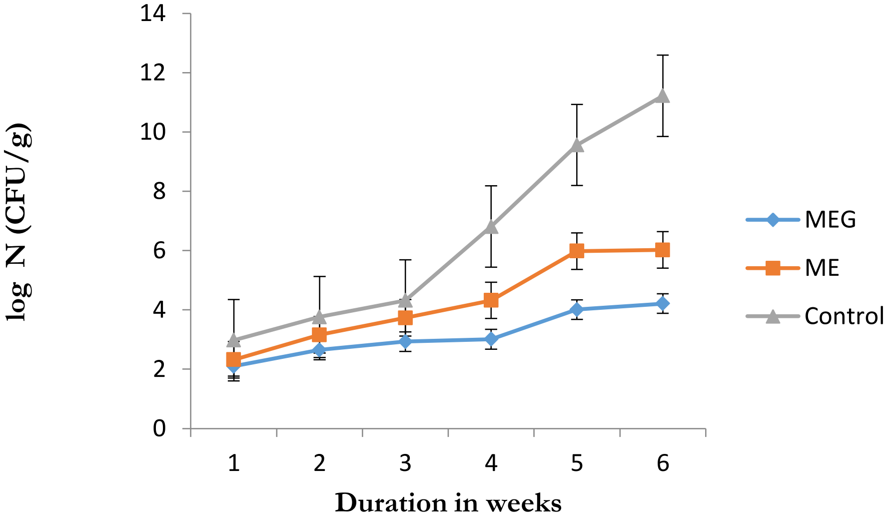

Fig. 6: Effect of MEG and ME on yeast and mold counts of papaya during storage in ECS.

Mesophilic Counts

Figure 7 shows the total mesophilic aerobic counts during storage of coated and uncoated papaya. The initial mesophilic microbial load in control samples from MEG and CMC were 2.32 and 2.51 log CFU/g, respectively, in the first week while that of the control was 2.26 log CFU/g. The mean ± S.E. value for the mesophilic aerobic counts of coatings from MEG and ME on papaya were 3.65 ± 0.43 and 4.45 ± 0.55 log CFU/g, respectively, while the mean ± S.E. value for the uncoated fruit was 5.74 ± 1.34 log CFU/g. Results revealed that the application of MEG and ME coating significantly reduced the total microbial counts in comparison to the uncoated samples. The results of mesophilic aerobic counts showed the effectiveness of MEG and ME as an antimicrobial agent. The antimicrobial action of coating materials has been reported by other authors in minimally processed garlic (Geraldine *et al.*, 2008) and fresh-cut cantaloupe and pineapple (Sangsuwan *et al.*, 2008). The control of decay in coated papaya could be attributed to the modified atmosphere originated by the edible coating from MEG and ME (Dutta *et al.*, 2009). Spanish regulations (BOE, 2001), established a maximum count level of 7 log CFU/g for aerobic mesophilic microorganisms in food samples. Also in this study the coated papaya with MEG and ME were able to hinder microbial growth to lower microbial loads of 4.98 and 6.32 log CFU/g, respectively, while the uncoated papaya had a higher microbial load of 9.78 log CFU/g.

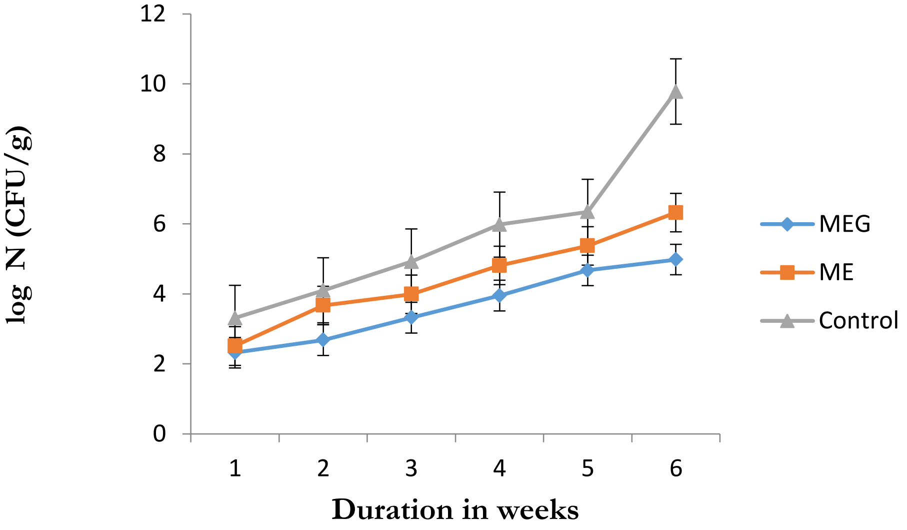

Fig. 7: Effect of MEG and ME on mesophilic counts of papaya fruit during storage in ECS.

Psychrotrophic Counts

The initial microbial load of psychrotrophs in the control samples from MEG and ME were 2.10 and 2.32 log CFU/g, respectively, in the first week while that of the control was 2.98 log CFU/g. Changes in the total aerobic psychrotrophic count in papaya are shown in Fig 8. The mean ± S.E. values for the aerobic psychrotrophic counts of coatings from MEG and ME on papaya were 3.15 ± 0.33 and 4.26 ± 0.61 log CFU/g, respectively, while the mean ± S.E. value for the uncoated was 6.44 ± 1.37 log CFU/g. The coated papaya with MEG and ME were able to hinder the growth of psychrotrophic microorganisms to a lower microbial loads of 4.21 and 6.02 log CFU/g, respectively, while the uncoated papaya had a higher microbial load of 11.22 log CFU/g because of the absence of any inhibiting substance to psychrotrophic microorganisms around the surface area of the papaya fruit. The predominant microflora which influences the shelf life of fruits and vegetables are psychrotrophic bacteria (Hotchkiss & Banco, 1992; Garcia-Gimeno and Zurera-Cosano, 1997).

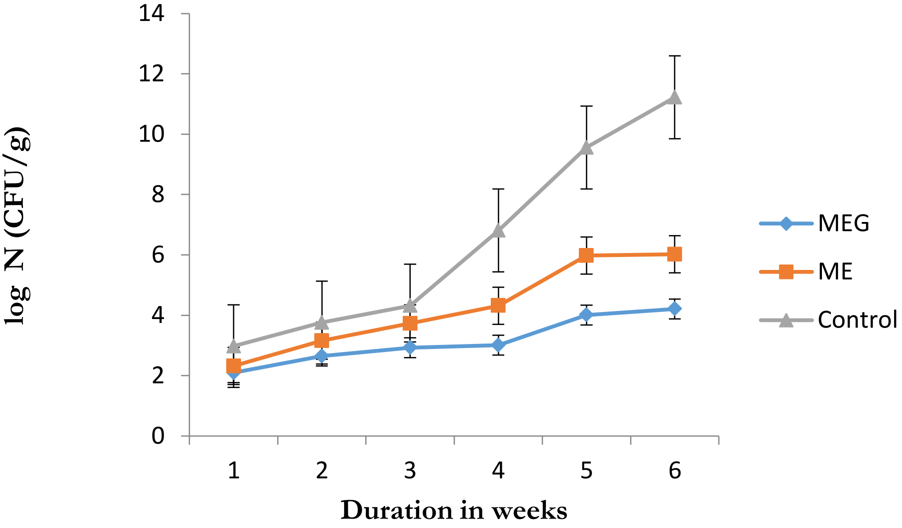

Fig. 8: Effect of MEG and ME on psychrotrophic counts of papaya fruit during storage in ECS.

CONCLUSION

Applications of *Opuntia* cactus mucilage coating to papaya were shown to be beneficial in keeping the quality of the fruits in storage. The edible coating from *Opuntia* cactus mucilage was able to reduce the ascorbic acid content, pH and the total soluble solids. The shelf-life of papaya fruits was increased at an average temperature of 27 ± 2 °C and relative humidity of 55-60%.

Textural analysis showed that prickly pear cactus mucilage may have a protective effect on papaya, as reflected by the greater firmness of coated samples during storage, which could reduce economic losses due to spoilage produced from mechanical damage during handling and transportation.

Finally, the overall result showed that *Opuntia* cactus mucilage in the order of MEG>ME is effective in extending the shelf-life of papaya fruits with the addition of plasticizers, which notably helped the coatings to bind to the surface of the papaya.

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