Journal of Animal & Plant Sciences, 32(1): 2022, Page: 292-300
ISSN (print): 1018-7081; ISSN (online): 2309-8694
https://doi.org/10.36899/JAPS.2022.1.0424

EFFECTS OF EDIBLE ALOE-PECTIN COATING AND HOT-AIR DRYING ON COLOR, TEXTURE AND MICROSTRUCTURE OF DRIED MANGO SLICES

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ABSTRACT

Mango fruit has a very short shelf life due to its climacteric nature and high moisture content. In this study, mango slices were dried to enhance its shelf life. Edible coating and osmotic dehydration were used as pretreatment followed by hot air dying as a final drying. Effects of coated and control osmotically dehydrated mango slices were investigated for shelf-life stability. Mango slices were coated by aloe-pectin solution (50% v/v aloe vera gel + 0.5w/v of pectin + 0.2w/v of calcium in distilled water) then osmotically dehydrated by immersing in 55% sucrose solution for 3 hours, and further dehydrated by hot air dryer at 65˚C. Samples were stored for 4 months and analyzed regularly after one month interval for shrinkage, rehydration, color change, texture and microstructure. At the end of storage, maximum shrinkage % of 45.18 and 42, rehydration ratio score of 1.7 and 2.87, mold and yeast count of 3.69 and 1.72 Log CFU/g was observed in control and coated samples, respectively. The results of present study revealed that during storage, coated samples maintained better microstructure, texture and color parameters as compared to control samples.

Keywords: Mango slices, Aloe-pectin, Shrinkage, Microstructure

Published first online June 14, 2021 Published final January 07, 2022.

INTRODUCTION

Mango (*Mangifera indica* L.), belongs to family *Anacardiaceae*, is one of the very valuable tropical fruits consumed worldwide and grown in tropical and sub subtropical zones in the world. It is the 2nd most valuable tropical fruit after banana, with production estimate of 45 million tons per year (FAOSTAT, 2017; Litz, 2009). South East Asia is considered as its origination region (Mukherjee, 1951; Usman, Fatima, Khan, & Chaudhry, 2003). Pakistan is the 4th major mango producing country in the world and mango is the second highest produced fruit after citrus in Pakistan (FAO, 2011).

Conventionally, the air-drying method is used to decrease the postharvest losses and increase the shelf life of fruits. However, the quality parameters such as color, flavor, nutritional contents, product texture, and rehydration ratio are negatively affected when high temperature and long drying time treatments are applied to fruits (Sun, Zhang, & Mujumdar, 2019). Osmotic drying (OD) is an important pretreatment method to overcome the undesirable effects of convective drying. It helps to maintain the cellular integrity, reduce the loss of heat-sensitive compounds, color, and flavor of fruits. Hence, it leads to better quality of the dry fruit products (Guiamba *et al*., 2016; Sulistyawati,Verkerk *et al*., 2020; Sakooei-Vayghan *et al*., 2020).

Osmotic dehydration is the process of immersing food into a hypertonic solution (salt, sugar, or an active physiological component) at a certain temperature and time. Due to the permeability of cell membrane, a chemical potential gradient develops between the dehydrating fruit cells and the surrounding hypertonic solution, which ease the water loss (WL) as well as the solid gain (SG) through osmotic and diffusion mechanisms(Andrés *et al*., 2007; Jiménez-Hernández *et al*., 2017; Rascón *et al*., 2018). Due to the low energy consumption, it is a cost-effective method and has been gaining wide acceptance over traditional drying methods (Khin, Zhou and Perera, 2005). Besides the advantages, OD has some disadvantages including 1) excessive sugar uptake which results in the candied texture of the products, and 2) leaching out of water-soluble vitamins, minerals, and organic acids during the process (Chandra and Kumari, 2015; Gulzar *et al*., 2018; Yadav and Singh, 2014). To overcome the undesirable effects of OD, samples are pretreated for making some edible semi-permeable membrane coatings on them. Fine layers of digestible materials such as lipids, proteins, and polysaccharides are used to form edible coatings on food products (Lago-Vanzela *et al*., 2013; Rahman *et al*., 2020). The drying conditions of OD (agitation, time, temperature, etc.) and the nature and concentration of coating materials have a conspicuous effect on the drying efficiency (Khin *et al*., 2005). Edible coating act as a barrier to oxygen and carbon dioxide, but a poor barrier to water and thereby help in retaining the aroma and flavor of foods by strengthening the cellular integrity to withstand the excessive osmotic pressure (Camirand *et al*., 1992; Nottagh *et al*., 2020).

Various types of food additives (colors, flavors, nutraceuticals, firming agents, plasticizers, preservatives, volatile precursors, and anti-browning agents) are in use to improve the organoleptic, functional and nutritional properties of coating materials (Baldwin *et al*., 1996; Bico *et al*., 2009). Polysaccharide-based coatings include pectin, alginate, chitosan, starch, methylcellulose, maltodextrin, carboxymethylcellulose, and carrageenan are used successfully for fresh cut fruits (Thommohaway *et al*., 2007). Aloe vera (A. vera) is a well-known plant for its therapeutic and medicinal properties from time as far back as roman ages (Crosswhite & Crosswhite, 1984; Morton, 1961). Recently it is getting popularity in the food business as a food component of ice cream, beverages and drinks (Moore and McAnalley, 1995; Valverde *et al*., 2005).

Osmotic dehydration alone usually not provide the shelf stable products of sufficiently low moisture content; therefore, this method is used prior to various drying procedures like freeze drying, vacuum drying and osmo-convective drying (Raoult-Wack, 1994; Rastogi *et al*., 2000; Torreggiani and Bertolo, 2004; Çağlayan and Barutçu Mazı, 2018). OD resulted in better quality and reduce shrinkage of products when used before conventional drying methods. Moreover, it reduces initial moisture upto 50% due to which time and energy cost of final drying is reduced (Chiralt *et al*., 2001).

Osmo-convective drying can be used at industrial level, the only by-product of sucrose osmotic dehydration is the spent solution which can be bio-transformed to develop other value-added products, as Spent solution of pineapple osmotic dehydration (after five runs) was used in the formulation of fruit dragée (Germer *et al*., 2017). Effluent from a commercial scale was revived and feed into a scheme of operation for ongoing OD of fruits and vegetables. This procedure is environment friendly and promises remarkable economic improvements if adopted in industry (Duduyemi, Ngoddy, & Ade-Omowaye, 2015).

The objective of this research was to study the effects of aloe-pectin coating on the storage stability of osmo-convective dried mango slices and quality of dried mango slices was evaluated by the physical and microstructure analysis during 4 months of storage at room temperature.

MATERIALS AND METHODS

Mango fruit (Chounsa variety) at harvest maturity level was obtained from the Mango Research Institute (MRI) Multan and brought to the laboratory in wooden cartons, stored for 5 to 6 days in controlled environments (25 ± 3 ˚C; 60 ± 3 RH) and were sorted visually for color, firmness, and physical damage. Aloe vera leaves were obtained from the National Herbarium of National Agriculture Research Center (NARC) Islamabad, Pakistan. This work was conducted in post-harvest laboratories of PMAS Arid Agriculture University Rawalpindi, Pakistan. Microbiological analysis was performed in the Institute of Plant and Environmental Protection (IPEP) of NARC and samples were shifted to McGill University, Canada for microstructure and texture analysis.

Sample Preparation: The mangoes were rinsed with chlorinated water in order to eliminate dust and dirt and were kept under fan to dry excessive surface water. These fruits were then manually peeled with a sharp knife and sliced approximately 0.8 to 1 cm thickness. Slices were blanched in boiling water for 30 seconds and immediately dipped in ice-cold water to prevent cooking.

Coating Treatment: Coating was prepared by using the method described by (Ramachandra & Rao, 2008) with some modifications. Aloe vera gel solution of 50% in distilled water was prepared with addition of 0.2% calcium chloride, 0.5% pectin. Mango slices were loaded in stainless steel perforated spoon and dipped for 1min, later drained and placed in hot air oven at 65 ˚C for 20 minutes to fix the coatings.

Osmotic Dehydration: Hypertonic solutions of 55 % sucrose were prepared in distilled water by continues stirring with magnetic stirrer at 70˚C with the addition of 0.5% citric acid and 0.25% of potassium metabisulfite (KMS). Mango slices were osmotically dehydrated in sucrose (55%) the ratio between mass of mango slices and osmotic solvent was kept at 1:10 to avoid substantial dilution of the osmotic solution due to mass exchange phenomena of osmotic dehydration. Osmotic dehydration was performed in stain less steel bowl covered by aluminum foil at 45˚C for 3 h. After osmotic dehydration excess solution was washed with distilled water and superficial water was drained by paper towel.

Hot air drying: After OD as described above the selected samples were further dried in cabinet or tray dehydrator (Arm field, Ringwood U.K.) at 65 ˚C air temperature and air velocity of 1.5m/s. To set the desired conditions of temperature the dryer was run for 30min without samples before each drying. Then the pre-treated samples were subjected for drying to arrive the moisture of 10% ± 3.

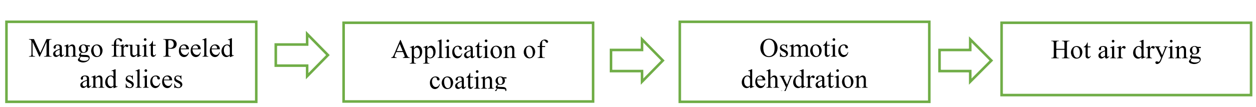

Figure 1. Flow diagram of processing of dried mango slices

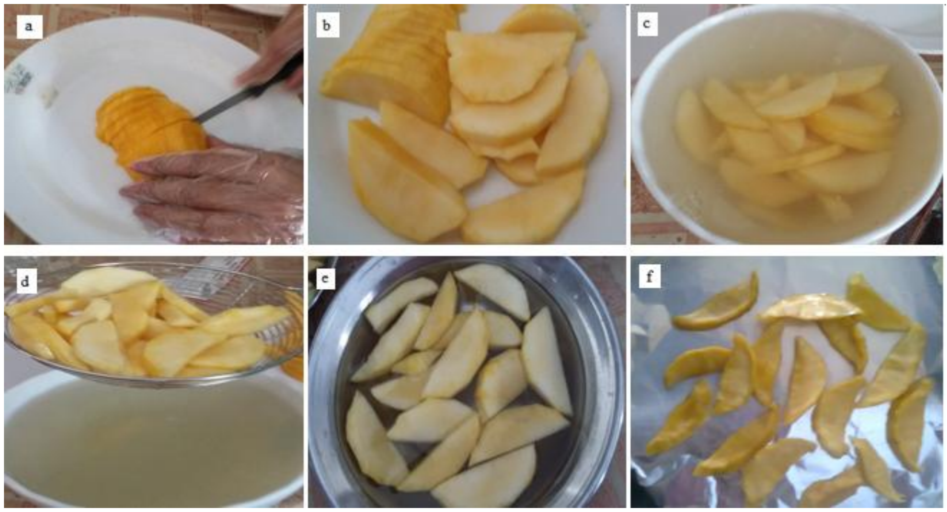

Figure 2: Photograph of fresh mango cutting (a,b), coating (c,d), osmotic dehydration (e), and final dried slices (f)

Shrinkage (%): The apparent volume ratio of mango slices before and after drying was taken by the displacement method, toluene was used as a solvent (Yan *et al*., 2008). Shrinkage was measured by using the following formula

$$\text{Shrinkage (\%)} = \frac{V}{V} \times 100$$

Rehydration Ratio (RR): The RR of dried mango slices samples were determined by immersion of dried mango slices (known weight) in water until reach the constant weight at room temperature (Mazza, 1983). Then the slices were drained with paper towel and measured its mass before and after the immersion by electronic balance. The rehydration ratio was calculated by the formula given below

$$RR = \frac{\text{W o r m s (g)}}{\text{W o d m s (g)}}$$

Microbiological analysis: Mango sample slices were analyzed for yeast and mold, *Salmonella spp.* and *Coliforms*. The salmonella spp. and Coliforms were analyzed directly after drying process to evaluate the hygienic environment of processing, whereas the yeast and mold counts was analyzed at regular intervals of one-month by the method of Downes and Ito (2001).

Change in color (ΔE): The total color change in samples was observed by using tristimulus colorimeter (Minolta Co. Ltd., Japan) by the measuring color parameters of L^* (lightness), a^* (redness), b^* (yellow). Total change in color was measured by Hunter-Scotfield equation.

$$\Delta \quad = \sqrt{(\Delta \quad)^2 + (\Delta \quad)^2 + (\Delta \quad)^2}$$

Where, $\Delta a^* = a^* - a^*_o$, $\Delta b^* = b^* - b^*_o$, $\Delta L^* = L^* - L^*_o$
Whereas the suffix 0 indicated the fresh samples

Texture Analysis: To measure the change in texture compression test was performed for dried mango slices. Analysis was performed at regular intervals of one month by using texture analyzer (Intron 4502, Boston, USA). Diameter of cylindrical prob used for puncture of dried mango slices was 3.7mm (Singh *et al*., 2013).

Microstructure Analysis: Small pieces of dried samples were taken and fixed on sticky carbon on rotatory holder. Insert the samples in the vacuum chamber. By using tabletop scane electon microscope (HITACHI TM3000) at the resolution of 500x to take the micrographs of dried mango slices surface.

Statistical Analysis: All the experiments were conducted in triplicate, the mean values with the standard deviations are shown as the results. The data was analyzed by factorial ANOVA (2x5 experiment levels) technique and significant treatment means were separated by post-hoc LSD (Least Significant Difference) test ($P \leq 0.05$) using the statistical software "statistics 8.1".

RESULTS AND DISCUSSION

Shrinkage (%), Rehydration Ratio and Microbiological Analysis: The physiological weight loss is attributed to shrinkage %, that is due to evaporation or transpiration of water through the surface tissues and other biological fluctuations which takes place in the mango slices. The results of shrinkage, rehydration and microbial count are shown in Table 1. Shrinkage % of 43.34 and 41.20 was observed in control and coated samples at the start of storage which increase with the increase in storage. Higher increase in shrinkage % was observed in control samples at the end of storage, while in coated samples slight increase was observed that might be due to the coating barrier on the surface which cause resistance of moisture evaporation.

Rehydration is an intricate procedure and designates the chemical and physical changes brought by dehydration. When placed the dried fruit slices into water, the cell walls absorb moisture. Then due to the biological flexibility of cells structure, they reimbursed to their unique form by pulling water into internal cell cavities. Results showed the maximum rehydration ratio of 3.15 in coated and 1.95 in control samples. Slightly lower rehydration ratio was resulted in control dried samples that might be due to break down in cellular structure. Such a performance is described in few similar studies about convective drying of sweet potatoes (Singh and Pandey, 2011). The relatively rapid rate of re-formation was observed in osmo-coated cabinet dried mango slices. This rapid water uptake is very likely due to surface suction strength (de Souza Silva *et al*., 2011; Singh and Pandey, 2011).

Treatments (control and coating) showed significant effect, whereas storage and interaction of treatments and storage illustrate non-significant effect on shrinkage % and rehydration ratio. That resulted in sustained quality of dried mango slices during storage months.

The growth of microorganism in fruit product is not only intolerable for consumer's health but it also affects the sensory quality of product. To check effectiveness of hygienic practices and the sanitization process the samples were analyzed for *Salmonella ssp.* and *Escherichia coli* group at the start of storage. *Salmonella spp.* was not found in both control and coated samples while the *Escherichia coli* were lower the detection limit of the procedure (Log CFU/g).

Furthermore, when the yeast and mold count exceed to 10^6 CFU/g it produces the toxic substances, this value is reflected as acceptable limit throughout storage study of fruit products (Lee *et al*., 2003). In the present study treatments, storage and their interaction showed significant effect on yeast and mold count (Table 1). The minimum yeast and mold count of 1. 39 Log CFU/g in control and 0.27 Log CFU/g in coated samples were observed at the beginning of storage as shown in Table 1. However, an increasing trend in CFU/g was observed along with the storage months. The increase of yeast and mold count in coated samples were lower than control at the end of storage, it might be due to the antimicrobial effect of polysaccharide-based coatings (Bico *et al*., 2009). Aloe vera gel, pectin and calcium chloride bargain a natural fungicidal effect to control postharvest fungal deterioration of agricultural produce and might be an attractive substitute to chemical fungicides (Saks and Barkai-Golan, 1995). In the present study the maximum yeast and mold count of 3.69 Log CFU/g was observed in control samples at the end of storage, which is below the permissible limit. Aloe-pectin coating is the one factor to reduce the microbial growth, the preservative, antioxidant (potassium metabisulfite, citric acid), sugar concentration used for osmotic dehydration before convective drying and decrease in moisture content with final drying also played an important role in making mango slices shelf stable at ambient temperature.

Table 1. Mean values for treatments (contol and coating) and storage (months) interaction of shrinkage (%), rehydration ratio, yeast and mold count (Log CFU/g).

Treatments	Storage months	Shrinkage	Rehydration	Yeast and mold count (Log CFU/g)
Control	0	43.34±0.31^{bcd}	1.95±0.78^{b}	1.39±0.15^{f}
	1	43.66±0.44^{abc}	1.9±0.34^{b}	2.09±0.04^{d}
	2	43.9±0.64^{ab}	1.8±0.64^{b}	2.87±0.11^{c}
	3	44.52±0.34^{ab}	1.75±0.73^{b}	3.45±0.10^{b}
	4	45.18±0.36^{a}	1.7±0.27^{b}	3.69±0.02^{a}
Coated	0	41.20±1.12^{e}	3.15±0.38^{a}	0.27±0.01^{i}
	1	41.23±0.56^{e}	3.1±0.12^{a}	0.65±0.05^{h}
	2	41.49±0.77^{e}	3.03±0.42^{a}	1.18±0.06^{g}
	3	41.74±0.30^{de}	2.95±0.18^{a}	1.62±0.12^{e}
	4	42±0.18^{cde}	2.87±0.29^{a}	1.72±0.18^{e}

(Column wise values showed by similar letters are not significatly different)

Change in color (ΔE): Color score of dried products is an important parameter to determine the consumer acceptance, edible polysaccharide-based coatings preserve the original fruit color by delaying browning (Chien and Yang, 2007). The average lightness (L^*), redness ($+a^*$) and yellowness (+b) color properties obtained for control and coated dehydrated mango slices are presented in Table 2. Results showed that the increase in storage months results in decrease of lightness, slight increase in redness and increase in degree of yellowness as the storage showed significant effect on b^*. For the dried samples the L^* presented the highest values in coated samples. However, the score of $a^*$and L^* for all control and coated is not significantly affected by storage time. On the contrary, significant ($p > 0.05$) difference is observed in the score of b^* between control and coated treatments. Increase in yellowness with the storage might be due to non-enzymatic browning, increase in yellowness in control sample was considerable while non-significant increase was observed in aloe-pectin coated samples along with storage intervals. Use of calcium chloride and active particles in aloe vera help preventing polyphenol oxidase activity. Pectin coatings are good barrier of oxygen and carbon dioxide resulted in delayed browning (Chiumarelli *et al*., 2011). The increase in storage time increases the non-enzymatic browning. Development of yellow brown color might be due to the Millard reaction or ascorbic acid degradation during thermal treatment (Chong *et al*., 2013; Gulzar *et al*., 2018; Korbel *et al*., 2013). Treatments showed significant effect on L^*, a^* and b^*. While the interaction of treatment and coating showed non-significant effect on color parameters (Table 2) resulted in sustained color of dried mango slices during storage months.

Table 2. Mean values for treatments (control and coating) and storage (months) interaction of color parameters.

Treatments	Storage months	L^*	a^*	b^*	ΔE
Control	0	39.94±2.47^{bc}	1.86±0.19^{a}	25.11±1.12^{d}	10.43±1.96^{bc}
	1	39.34±2.59^{bc}	1.99±0.29^{a}	25.46±1.30^{cd}	10.31±1.33^{bc}
	2	38.44±0.89^{cd}	2.01±0.74^{a}	27.91±1.41^{bc}	11.88±0.43^{ab}
	3	37.22±1.12^{cd}	1.87±0.43^{a}	29.49±1.54^{b}	12.10±0.52^{ab}
	4	35.52±1.53^{d}	1.89±0.30^{a}	32.14±1.89^{a}	13.07±1.83^{a}
Coated	0	44.39±2.21^{a}	0.91±0.17^{b}	20.16±1.55^{f}	8.98±1.05^{c}
	1	44.94±2.15^{a}	0.93±0.01^{b}	19.62±1.67^{f}	9.01±0.67^{c}
	2	43.55±0.74^{a}	0.95±0.15^{b}	21.97±1.32^{ef}	9.99±1.59^{bc}
	3	42.46±2.16^{ab}	0.99±0.36^{b}	23.13±0.72^{de}	10.10±1.86^{bc}
	4	42.47±1.55^{ab}	0.97±0. 56^{b}	23.33±2.17^{de}	10.29±1.36^{bc}

(Column wise values showed by similar letters are not significatly different)

Texture: Texture is a significant trait required by consumers and most of time is responsible for dried fruit acceptability. Table 3 shows the textural parameters for control and aloe-pectin coated samples. Texture firmness is accompanying with force used to puncture the sample (Tello *et al*., 2011; Vega-Gálvez *et al*., 2011). Treatments (control and coating) showed significant effect on puncture force (N) and energy (J). It can be observed that the higher energy and force is required to puncture the control samples as compare aloe-pectin coated from 0day to end of storage months. The reason for this can be the lowest final moisture contents in control samples (non-coated) while edible coated samples had slightly higher values of final moisture contents within the same time of dehydration, coating layers provide resistance in evaporation of water from the surface as a result the out-ward passage of moisture from the interior of the sample decrease. Mango slices showed an increasing tendency of average firmness in both coated and control samples, But the increase in firmness in control samples is higher than coated samples at the end of storage. This might be due to the higher moisture loss due to surface evaporation from control samples, while the coating treatment prevent the evaporation of moisture and better maintain the texture during storage at room temperature. Results are in line with previous findings of quince slices (Akbarian *et al*., 2013).

The interaction of treatment and storage showed non-significant effect on texture (Table 3). From the present study it is concluded that overall texture of all treatments was acceptable that might be due to the pretreatments of coating and osmotic treatment, effect of sugar and acid (low molecular weight solutes) absorbed by these pretreatments can be the reason of soft texture, enhancing the flexibility of biopolymer chains in the food assembly and decrease the mechanical strength. It is showed that there would possibly a substantial difference between samples, which have been treated prior to drying (Akbarian *et al*., 2015; Askari and Emam, 2006).

Sensory score of dried mango slices were observed and statistically non-significant change in color, flavor and overall acceptability was observed along with the storage months in both control and coated treatments. Hence, the coated osmo-convective drying can make the best quality dried fruit available throughout the year. Reduction in weight and volume of dried product resulting in decreasing price of packaging, transport and storage at industrial level by eliminating the operation cost of cold sotage during full-length suply chain (Miranda, Berna, & Mulet, 2019; Hasan *et al*., 2019).

Microstructure: Microstructure of dried mango slice surface was analyzed by scan electron microscope to find the effect of aloe-pectin coating on morphology of surface cells. Figure 2 shows the micrograph of coated and control samples along with storage months, at 0day coated dried sample showed well-arranged, orderly structured cells and intercellular spaces (Fig. 2a). After 2nd month cells seem to be slightly contracted (Fig. 2b) and after 4th month more deformed and contracted cells were showed due to evaporation of water (Fig. 2c). The more porous and well-arranged cell structure can be seen in coated sample in contrast to control. While at 0day the highly collapsed and damaged surface cells were observed in control showed by arrows (Fig. 2d). After 2nd and 4th months cells seem to be highly deformed and contracted with collected sugar particles. This is perhaps related to the elimination of more vapor from surface in drying process, the cellular collapse in the control samples is more pronounced in contrast with the aloe-pectin-coated slices. That might be due to coating before osmotic and final convective drying. In the control samples, maximum solid uptake was promoted by the pressure gradients developed by hypertonic solution of sucrose. Consequently, replacement of water by sucrose particles contributed to the breakdown of the cells. These results are in line with previous findings of Akbarian *et al*., 2015.

Table 3. Mean values for treatments (control and coating) and storage (months) interaction of texture parameters.

Treatments	Storage months	Force (N)	Energy (J)
Control	0	30. 169±1.138^{de}	0.043±0.002^{bcd}
	1	33. 509±2.016^{c}	0.045±0.004^{abcd}
	2	35.255±1.380^{b}	0.048±0.007^{abc}
	3	33.911±0.692^{bc}	0.050±0.005^{ab}
	4	37.107±1.583^{a}	0.052±0.003^{a}
Coated	0	26.840±1.117^{f}	0.040±0.004^{d}
	1	27.650±1.456^{f}	0.041±0.008^{cd}
	2	28.514±0.867^{ef}	0.041±0.002^{cd}
	3	29.370±1.997^{de}	0.043±0.003^{bcd}
	4	30.294±1.340^{d}	0.043±0.001^{bcd}

(Column wise values showed by similar letters are not significatly different).

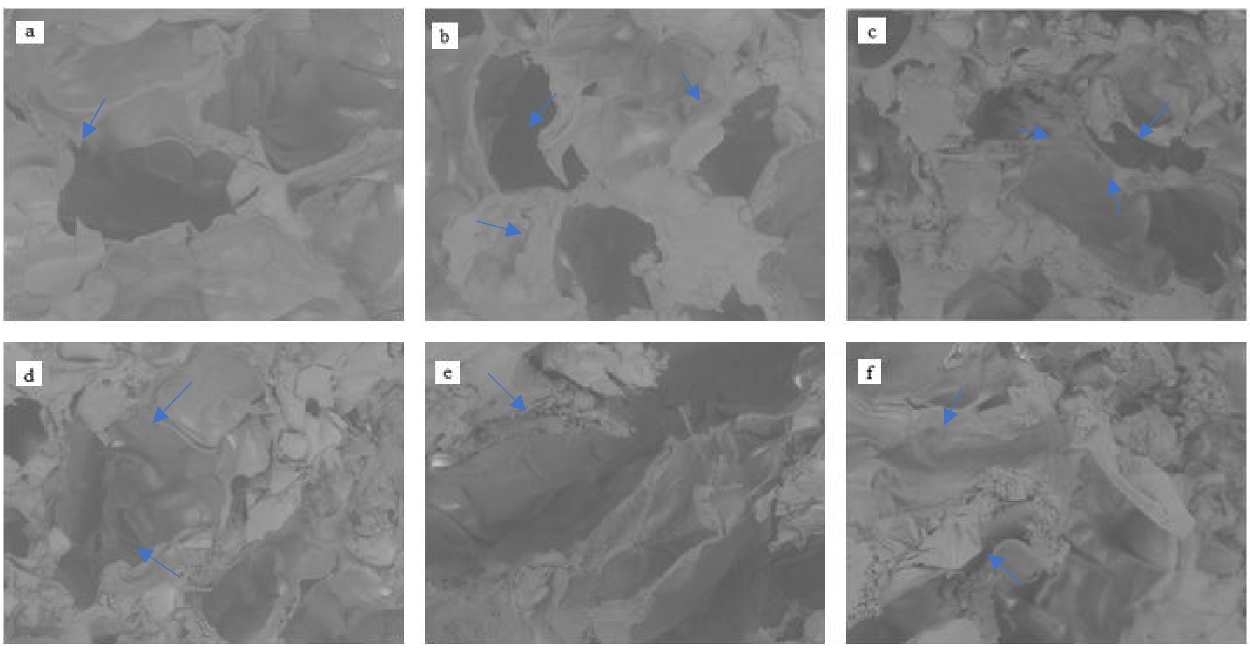

Figure 3: Micrograph of mango parenchyma slices surface during storage at ambient temperature. a-c aloe-pectin coated samples, d-f control (without coated) samples, a, b and c are the images of coated samples at 0, 2nd and 4th month of storage, d, e and f are the images of control samples at 0, 2nd and 4th month of storage.

Conclusion: From the results it is concluded that shrinkage, rehydration, microbial analysis, color, texture and microstructure is significantly affected by the aloe-pectin coating. Aloe-pectin coating is the good barrier of moisture evaporation within samples during storage and resulted in comparatively softer texture, higher rehydration ratios and prevents excessive shrinkage in coated slices. Color of coated samples remained more consistent during storage as contrary to control samples. Microstructure clearly showed the less collapse in cell structure. Hence, the dried mango slices were analyzed by using different quality and safety parameters and found not heath threatening for consumers, if dried at industrial level it would be the best value addition of dried snack of mango in Pakistan and will also be helpful to prevent post-harvest losses.

Acknowledgements: We are cordially thankful to International research support initiative program of HEC Pakistan, Institute of plant and environmental protection (IPEP) NARC, Islamabad.

Conflict of interest: All authors declare no conflict of interest

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