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EFFECTS OF MATURITY ON PHYSICOCHEMICAL PROPERTIES OF OSMOTICALLY DEHYDRATED MANGO CUBES

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ABSTRACT

Effect of different ripening stages on the physicochemical properties of osmotic dehydrated mango cubes (var. Chonsa) was investigated. Osmotic dehydration was performed at 50°C for 2 hours using 45, 55 and 65˚Brix osmotic solutions. Water Loss (WL), Solute Gain (SG) and Dehydration Efficiency Index (DEI) found to be dependent on the maturity stage. Partially-ripe mango cubes showed highest WL and SG but revealed low DEI. Shrinkage and Firmness revealed non-linear correlation with increasing maturity. Dehydrated mango cubes shrank more and found harder at 55°Brix. Mango cubes dehydrated at 45 and 55°Brix showed significant variation in physicochemical properties.

Keywords: Osmotic Dehydration, Mango, Dehydration Efficiency Index, Firmness, Shrinkage.

INTRODUCTION

Mango (*Mangifera indica* L.) is an important tropical fruit of Pakistan produced 1.845 million metric tons in 2009-10 (FBS, 2011; Khan *et al*., 2008a). Pakistan ranked 5th largest producer of mango followed by India, China, Thailand and Indonesia (FAOSTAT, 2009; FBS, 2011). Mango preserved by traditional drying techniques found less marketable as a result of stale flavor, altered appearance, undesirable texture and loss of nutrients (Torres *et al*., 2006). Osmotic dehydration is a low energy minimal pre-treatment performed prior to other drying techniques to produce intermediate moisture ready-to-eat products having superior organoleptic characteristics (Chiralt and Talens, 2005; Khan *et al*., 2008b; Madamba and Lopez, 2002). In this treatment, cellular foods are partially dehydrated by immersing in concentrated osmotic solution of low water activity made by dissolving sugars, salts, organic acids, humectanats, electrolytes and preservatives (Ponting *et al*., 1966; Raoult-Wack *et al*., 1991). The rate of mass transfer and resulting dehydration depends upon osmotic solution (composition, concentration, solubility, viscosity), process conditions (time, temperature, pressure, agitation), nature of food to be dehydrated (composition, maturity, porosity, dimensions, geometry), pre-treatment of food (blanching, coating, freeze-thaw, peeling), and ratio of food and osmotic solution (Chiralt and Talens, 2005; Tedjo *et al*., 2002).

Osmotic dehydration of mango has been researched to understand the process kinetics as a function of time and temperature (Torezan *et al*., 2004), sucrose concentration and temperature (Alakali *et al*., 2006; Sagar and Suresh Kumar, 2009), atmospheric pressure and vacuum (Giraldo *et al*., 2003), frozen storage (Rincon and Kerr, 2010) and process optimization (Madamba and Lopez, 2002). However, no attempts have been made to study the effects of mango maturity on the physicochemical properties of dehydrated product. Maturity is important as harvesting of fruits largely depends upon it which in turn affect postharvest life and quality. Mango is a climacteric fruit generally harvested at physiological maturity but consumed as a fresh fruit after attaining horticulture maturity (Jha *et al*., 2006). Hence harvesting maturity of mango depends upon intended use and could be different if proposed for osmotic dehydration.

The present work was conducted to study the influence of maturity on the physicochemical properties of osmotically dehydrated mango cubes. Efforts were aimed to determine optimum mango maturity most favorable for osmotic dehydration. The use of osmotic dehydration should hopefully facilitate of mango.

MATERIALS AND METHODS

Unripe mangoes (var. Chonsa) were purchased from the wholesale market (Super Highway, Karachi) and transported to the laboratory in wooden boxes. Sucrose and Sodium hydroxide were purchased from Merck, Germany.

Maturity

Mangoes were allowed to ripe for 5 days at 30 ± 2˚C with 65 ± 3 % RH. Total Soluble Solids (TSS) and Total Titratable Acidity (TTA) were determined on a daily basis to calculate Maturity Index (MI = TTS/TTA). Abbe digital re-fractometer (ATAGO DR-A1, Japan) was used to measure TSS (˚Brix) of filtered mango juice (AOAC 932.14). TTA was determined by titration using standard alkali (0.1 M NaOH) to an endpoint of pH 8.2 (AOAC 942.15). Mangoes were classified and on the basis of firmness and Maturity Index (Mitcham and McDonald, 1992); mature-green (MI 37.72), partially-ripe (MI 72.85), firm-ripe (MI 131.39), soft-ripe (MI 157.61) and over-ripe (MI 165.38).

Sample Preparation

Each day, 20 mangoes were taken and thoroughly washed with tap water, dried and peeled off by hand-peeler. Mangoes were cut in to two longitudinal halves close to the fruit stone and then sliced in to 5 mm thick cubes of 2.5 cm length and width (Torezan *et al*., 2004). Mango cubes were distributed on absorbent paper to remove surface juice and used immediately for OD.

Physicochemical Properties

Total solids (%) of mango cubes were determined by oven-drying at 70˚C (AOAC 920.151) to calculate Solute Gain (Torezan *et al*., 2004). Water loss was also calculated per gram of initial dry matter and expressed as percentage to avoid moisture variation due to increasing maturity (Matuska *et al*., 2006). Shrinkage was quantified by taking ratio of apparent volumes of mango cubes before and after dehydration while apparent volumes were determined by displacement technique using toluene as a solvent (Yan *et al*., 2008)

$$SG\ (\%) = Ws_f\ (\%) - Ws_i\ (\%) \qquad \text{(i)}$$

$$WL\ (\%) = [m_o (1 - s_o) - m_k (1 - s_k)] \qquad \text{(ii)}$$

$$\text{Shrinkage}\ (\%) = V_d / V_o \times 100 \qquad \text{(iii)}$$

$$\text{Apparent Volume}\ (V) = V_f - M_{sf} / \rho_s \qquad \text{(iv)}$$

$$DEI = WL / SG \qquad \text{(v)}$$

Where;

Ws_i	Total solids before OD
Ws_f	Total solids after OD
m_o	Weight of mango before OD
s_o	Weight of initial solids in mango before OD
m_k	Weight of mango after OD
s_k	Weight of final solids in mango after OD
V_o	Apparent volume of mango before OD
V_d	Apparent volume of mango after OD
V_f	Volume of volumetric flask
M_{sf}	Weight of solvent added to fill volumetric flask
ρ_s	Density of solvent

Mango firmness was determined by simple compression test using Universal Testing Machine (Zwick GmbH & Co, Ulm, Germany). Mango cubes were compressed by stainless steel probe of 10 mm diameter at the test speed of 150 mm/minute to achieve 3 % strain. Pre-load was 0.2 N (10 mm/minute) to minimize the effect of uneven surface of mango cubes.

Statistical Analysis

All tests were performed in triplicate and results were reported as mean with standard deviation. The data was subjected to analysis of variance (ANOVA) followed by Duncan’s test using SPSS 17.0. Pearson's correlation coefficients were also determined. All statistical tests were carried out at significance level of $p \leq 0.05$.

Abbreviation

OD	Osmotic Dehydration
OS	Osmotic Solution

WL	Water Loss (%)
SG	Solute Gain (%)
DEI	Dehydration Efficiency Index
MI	Maturity Index
TSS	Total Soluble Solids
TTA	Total Titratable Acidity

RESULTS AND DISCUSSION

Maturity Index and firmness of fresh mango cubes with increasing maturity are presented in figure 1 and 2 respectively. As expected, MI increased while firmness decreased with increasing maturity.

WL revealed 2nd order polynomial association with increasing maturity at 45 (R^2= 0.99), 55 (R^2= 0.97) and 65˚Brix (R^2= 0.85) (Table 1). WL increased considerably in partially-ripe and firm-ripe mango cubes compared with mature-green followed by decline in soft-ripe and over-ripe mango cubes. Partially-ripe mango cubes dehydrated at 55˚Brix revealed maximum WL while unripe mango cubes at 45˚Brix had minimum. No significant difference in WL was observed between soft-ripe and over-ripe mangoes at 45 and 55 ˚Brix. WL also showed dependence on the concentration of OS (Table 1). For example, increase in concentration gradient (45, 55 and 65˚Brix) augmented WL significantly in mature-green mango cubes (48.04 %, 60.49 %, and 51.88 %) at $p \leq 0.05$. Mango tissues experienced a greater driving force by increasing concentration of osmotic solution as evident by increase in WL. However, a proportional increase in WL was not seen at 65˚Brix as resistance caused by case hardening of surface tissues diminished the driving force created by concentration gradient (Giraldo *et al*., 2003). WL of firm-ripe mangoes showed insignificant variation with increasing concentration of OS.

SG showed polynomial trends with increasing maturity at 45 (R^2 = 0.99), 55 (R^2 = 0.60) and 65 °Brix (R^2 = 0.99) (Table 1). SG depends upon the characteristics of the plant tissues (Giraldo *et al*., 2003) while increasing maturity also changed membrane permeability (Prasanna *et al*., 2007). It was revealed that partially-ripe mango cubes gained more solutes compared with soft-ripe. Mango is a climacteric fruit, ripe with dramatic change in chemical composition. TSS of mango increased abruptly (16.67 to 19.67°Brix) due to enzymatic hydrolysis of storage polysaccharides (starch) and subsequently increased neutral sugars particularly sucrose (Prasanna *et al*., 2007; Rincon and Kerr, 2010). Hence, increased cellular concentration reduced concentration gradient (driving force) between mango tissues and OS. Conversely, SG found higher for partially-ripe mangoes (Alakali *et al*., 2006; Rincon and Kerr, 2010). SG also varied with the concentration of OS (Table 1). Mature-green, partially-ripe, firm-ripe and soft-ripe mango cubes dehydrated at 55°Brix gained more solutes at 95 % confidence level compared with 45˚Brix. Mango tissues are comparatively porous; hence uptake of osmotic solution by Hydrodynamic mechanisms was substantial (Rincon and Kerr, 2010). Hydrodynamic gain was limited at 45°Brix due to low viscosity as evident by less SG (Giraldo *et al*., 2003). Further increase in concentration (65 °Brix) did not increase SG to considerable level. SG increased quickly at 55 and 65°Brix due to capillary diffusion and surface retention of OS but as OD continued, fruit pores immersed at 65 °Brix expelled OS as surface cells started to lose water and intercellular spaces squeezed (Giraldo *et al*., 2003). Over-ripe mangoes showed statistically similar SG with increasing concentration of OS. In general, maximum SG (46.67 %) was recorded for partially-ripe mangoes dehydrated at 55˚Brix while mature-green mangoes had gained minimum solutes (19.13 % at 45˚Brix).

The DEI of dehydrated mango cubes changed with maturity (Table 1). Partially-ripe mango cubes had low DEI similar to over-ripe but their SG was different. Partially-ripe mango cubes revealed considerably high SG while over-ripe had low (Figure 3). Partially-ripe mango cubes had high WL but it was accompanied by high SG leading to unsuitable choice for OD as revealed by low DEI. Mature-green mango cubes showed high DEI than soft-ripe due to less SG at 45°Brix. On the other hand at 55°Brix, DEI of mature-green mango cubes found similar to soft-ripe due to same amount of SG. Increasing maturity showed no significant variation in DEI at 65˚Brix despite of considerable variation in WL and SG. DEI of mature-green and partially-ripe mango cubes modified with increasing concentration of OS while firm-ripe, soft-ripe and over-ripe varied insignificantly (Table 1). DEI found higher for mango cubes dehydrated at 45 and 65˚Brix revealing mass transfer more favorable for WL. At 55˚Brix, mangoes dehydrated maximally but they also gained considerable solutes as revealed by low DEI. DEI of soft-ripe and over-ripe mango cubes varied insignificantly with increasing concentration. Overall, partially-ripe mango cubes dehydrated at 55˚Brix showed lowest DEI while mature-green (45°Brix) and firm-ripe (55°Brix) showed highest.

Table 1. Physicochemical Properties of Osmotic Dehydrated Mango Cubes.

Properties	OS	Mature-green Day 1	Partially-ripe Day 2	Firm-ripe Day 3	Soft-ripe Day 4	Over-ripe Day 5
Water Loss (WL %)	45˚Brix	48.04 ± 0.44 ^{a,1}	65.92 ± 1.2 ^{a,3}	65.22 ± 1.72 ^{a,3}	52.11 ± 0.31 ^{a,2}	54.15 ± 0.58 ^{a,2}
	55˚Brix	60.49 ± 0.08 ^{c,2}	68.35 ± 0.2 ^{b,4}	64.16 ± 0.45 ^{a,3}	56.88 ± 1.42 ^{b,1}	56.43 ± 0.1 ^{b,1}
	65˚Brix	51.88 ± 0.56 ^{b,1}	63.92 ± 0.15 ^{a,3}	65.94 ± 0.87 ^{a,4}	51.61 ± 1.56 ^{a,1}	56.81 ± 1.05 ^{b,2}
Solute Gain (SG %)	45˚Brix	19.13 ± 1.18 ^{a,1}	38.05 ± 0.43 ^{a,4}	31.25 ± 0.35 ^{a,3}	23.37 ± 1.51 ^{a,2}	31.09 ± 1.35 ^{a,3}
	55˚Brix	31.55 ± 0.0 ^{b,1}	46.67 ± 0.5 ^{b,3}	38.59 ± 0.39 ^{b,2}	31.3 ± 1.67 ^{b,1}	33.85 ± 1.11 ^{a,1}
	65˚Brix	30.5 ± 1.850 ^{b,1}	37.39 ± 0.43 ^{a,2}	34.0 ± 0.37 ^{a,12}	28.96 ± 0.58 ^{b,1}	32.2 ± 1.20 ^{a,12}
DEI	45˚Brix	2.51 ± 0.17 ^{b,3}	1.80 ± 0.13 ^{b,1}	2.09 ± 0.19 ^{b,2}	2.23 ± 0.12 ^{a,2}	1.74 ± 0.04 ^{a,1}
	55˚Brix	1.91 ± 0.01 ^{a,3}	1.46 ± 0.0 ^{a,1}	1.66 ± 0.12 ^{a,2}	1.81 ± 0.05 ^{a,23}	1.66 ± 0.05 ^{a,2}
	65˚Brix	1.70 ± 0.08 ^{a,1}	1.70 ± 0.01 ^{b,1}	1.94 ± 0.03 ^{b,1}	1.78 ± 0.03 ^{a,1}	1.76 ± 0.09 ^{a,1}
Shrinkage (%)	45˚Brix	49.95 ± 0.37 ^{a,3}	48.10 ± 0.89 ^{a,3}	43.16 ± 0.5 ^{b,1}	51.23 ± 0.51 ^{a,4}	44.99 ± 0.48 ^{a,2}
	55˚Brix	52.13 ± 0.81 ^{b,4}	48.90 ± 0.51 ^{a,3}	41.55 ± 0.61 ^{a,1}	51.34 ± 0.51 ^{a,4}	44.65 ± 0.1 ^{a,2}
	65˚Brix	52.05 ± 0.84 ^{b,4}	48.30 ± 0.82 ^{a,3}	41.70 ± 0.51 ^{a,1}	56.09 ± 1.54 ^{b,5}	44.91 ± 0.49 ^{a,2}
Firmness (N)	45˚Brix	64.38 ± 0.15 ^{a,1}	68.69 ± 0.52 ^{a,2}	128.1 ± 0.74 ^{a,2}	118.1 ± 0.51 ^{a,2}	66.28 ± 0.95 ^{a,1}
	55˚Brix	120.86 ± 1.6 ^{c,1}	153.7 ± 1.26 ^{b,3}	152.2 ± 1.33 ^{c,3}	134.11 ± 1.9 ^{b,2}	112.29 ± 2.2 ^{b,1}
	65˚Brix	76.62 ± 2.15 ^{b,1}	142.3± 2.18 ^{b,3}	139.2 ± 1.12 ^{b,3}	106.30 ± 2.6 ^{a,2}	66.40 ± 1.8 ^{a,1}

Different letters and numbers in a column and row respectively specify significant difference at $p \leq 0.05$

Shrinkage in dehydrated mango cubes fluctuated with increasing maturity (Table 1). The cell walls of parenchyma cells (mango pulp) are developed by biopolymers of diverse chemical nature (Pectins, Cellulose, Hemi-cellulose and Lignin). Fruit ripening degraded these biopolymers by respective enzymes and their structural-functional characteristics are modified as evident by change in shrinkage at different maturity stages (Prassana, 2007). Increase in maturity (mature-green, partially-ripe and firm-ripe) showed a linear decrease in shrinkage at 45, 55 and 65˚Brix followed by abrupt increase in line with optimum maturity (soft-ripe). Increase in maturity brought changes in cell wall (thickness, hydration) thus creating more intercellular spaces and weaken structural organization leading to high shrinkage (Prasanna *et al.*, 2007) Shrinkage reduced considerably in over-ripe mangoes. Mangoes dehydrated at 55˚Brix shrank more than 45˚Brix. Gas phase filled the intercellular spaces within porous mango tissues and developed an internal pressure. The osmotic pressure gradient altered the internal pressure which affect Hydrodynamic mechanisms. Mango tissues experienced more pressure gradient at 55˚Brix and accelerated the hydrodynamic mechanisms leading to higher impregnation of osmotic solution. Cells dehydrated and deformed to a greater extent due to high concentration gradient contributing higher shrinkage at 55˚Brix (Giraldo, 2003). A proportional increase in shrinkage was not observed at 65˚Brix due to case hardening and expulsion of osmotic solution leaving more intercellular space for gas phase and regain in tissue volume (Fito, 2002; Chiralt 2005). Moreover, OD increased tissue porosity and created more intercellular spaces occupied by dense liquid phase (55˚Brix) which substantially decrease cell volume (Giraldo *et al.,* 2003). This effect was not seen at 45˚Brix as gas phase was more dominant due to low viscosity of liquid phase. No effect on shrinkage was observed in partially-ripe and over-ripe mangoes at 45, 55 and 65˚Brix.

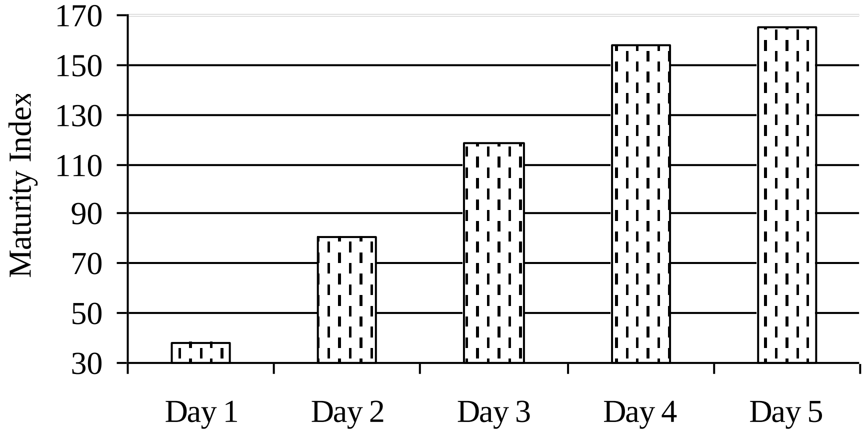

Fig. 1. Maturity Index of fresh mango with increasing maturity.

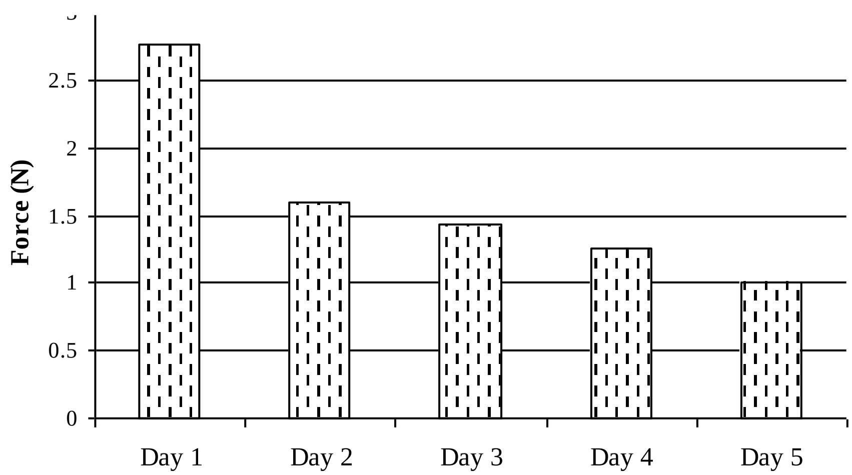

Fig. 2. Firmness of fresh mango with increasing maturity.

Firmness of dehydrated mango cubes changed with the maturity. Partially-ripe, firm-ripe and soft-ripe mango cubes revealed hard texture than mature-green at 45, 55 and 65˚Brix while over-ripe showed decreased firmness. Mangoes dehydrated at 55˚Brix were significantly firmed than 45˚Brix. OD increased the porosity in mango tissues and this effect was more pronounced at 55˚Brix (Barat *et al.,*1998; Fito *et al.,* 2002). High concentration gradient at 55˚Brix deformed cells to a greater extent due to high WL followed by cell wall relaxation leading to suction of osmotic solution. High pressure gradient at 55˚Brix proportionally increased this Hydrodynamic effect and regain of turgor pressure was evident by increased firmness. Mangoes dehydrated at 65˚Brix were less hard than 55˚Brix as Hydrodynamic mechanism was limited due to high viscosity leading to less SG. However, rigidity of surface cells dehydrated at 65˚Brix caused more firmness than at 45˚Brix due to case hardening (Giraldo *et al.,* 2003).

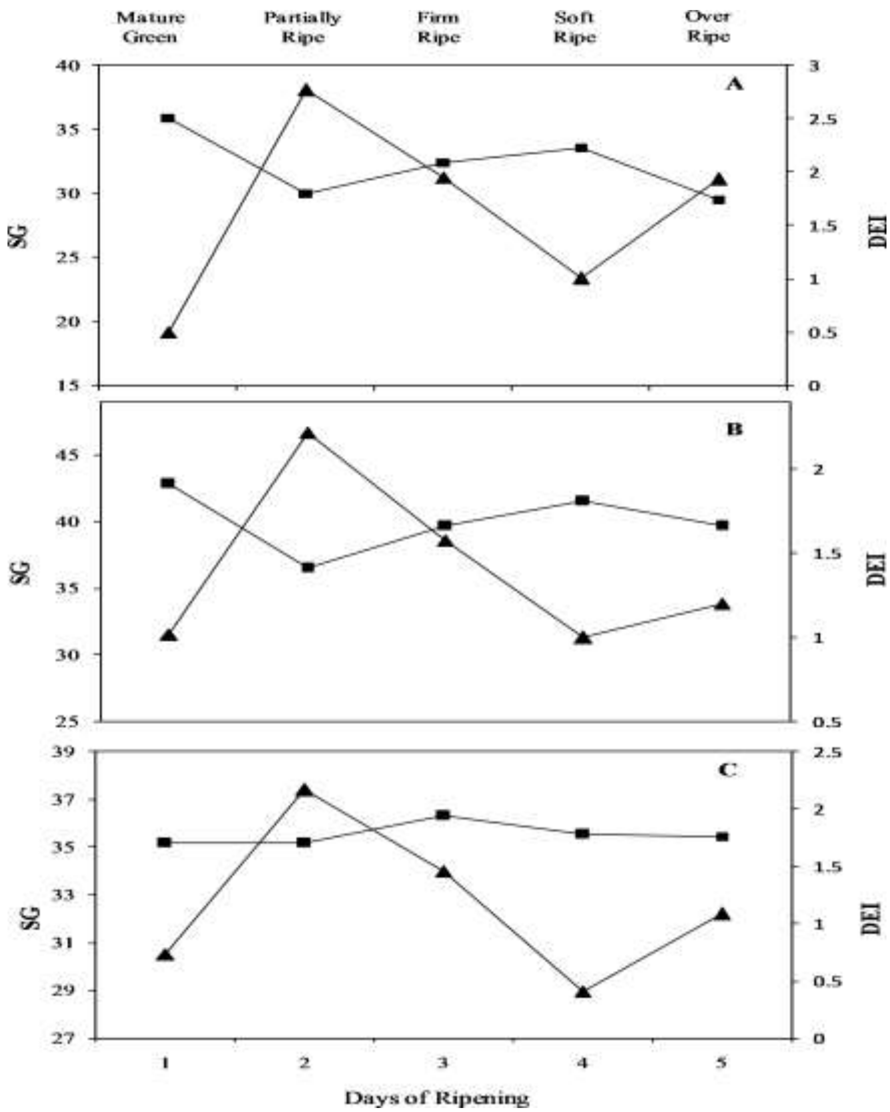

Fig. 3. SG ( ) and DEI ( ) of Dehydrated Mango Cubes at 45 (A), 55 (B) and 65 (C) °Brix

Conclusion

1. Appropriate maturity stage is of paramount importance as it significantly affects physico-chemical properties of osmotically dehydrated mango cubes.
2. Increasing concentration of OS modified physico-chemical properties of dehydrated mango cubes.
3. WL, SG, Shrinkage and firmness of dehydrated mango cubes were found to be highest at 55°Brix OS.
4. DEI was found to be associated with mango maturity. WL and SG both increased simultaneously in dehydrated mango cubes but their relative proportion depended upon the maturity stage of mango.
5. Partially-ripe mango cubes revealed highest WL and SG but corresponded to low DEI while firm-ripe had high WL and SG but their DEI found higher similar to soft-ripe mango cubes.
6. DEI remained unchanged with increasing maturity at 65°Brix.

REFERENCES

Alakali, J.S., C.C. Ariahu and N.N. Nkpa (2006). Kinetics of osmotic dehydration of mango. *Journal of Food Processing and Preservation*, 30(5): 597-607.

AOAC (2000). *Official methods of analysis of AOAC international*. Gaithersburg, MD, USA.

Barat, J., A. Chiralt and P. Fito (1998). Equilibrium in cellular food osmotic solution systems as related to structure. *Journal of food science,* 63(5): 836-840.

Chiralt, A. and P. Talens (2005). Physical and chemical changes induced by osmotic dehydration in plant tissues. *Journal of Food Engineering,* 67(1-2): 167-177.

FAOSTAT (2009). *Agricultural Production*. Food & Agriculture Organization of the United Nations.

FBS (2011). *Agriculture Statistics*. Federal Bureau of Statistics, Government of Pakistan.

Fito, P., A. Chiralt, J. Barat and J. Martınez-Monzó (2002). Mass transport and deformation relaxation phenomena in plant tissues, in: Welti-chanes, J., Barbosa-Canovas, G., Aguilera, J.M. (Eds.), *Engineering and food for the 21st Ccentury*. CRC Press, Boca Raton, pp. 235-254.

Giraldo, G., P. Talens, P. Fito and A. Chiralt (2003). Influence of sucrose solution concentration on kinetics and yield during osmotic dehydration of mango. *Journal of Food Engineering*, 58(1): 33-43.

Jha, S.N., A.R.P. Kingsly and S. Chopra (2006). Physical and mechanical properties of mango during growth and storage for determination of maturity. *Journal of Food Engineering,* 72(1): 73-76.

Khan, M., K. Mustafa, M. Shah, N. Khan and J.Z. Khan (2008a). Forecasting Mango Production in Pakistan an Econometric Model Approach. *Sarhad Journal of Agriculture,* 24(2): 363-369.

Khan, M.A.M., L. Ahrné, J.C. Oliveira and F.A.R. Oliveira (2008b). Prediction of water and soluble solids concentration during osmotic dehydration of mango. *Food and Bioproducts Processing*, 86(1): 7-13.

Madamba, P.S. and R.I. Lopez (2002). Optimization of the osmotic dehydration of mango (*Mangifera indica* L.) slices. *Drying Technology*, 20(6): 1227-1242.

Matuska, M., A. Lenart and H.N. Lazarides (2006). On the use of edible coatings to monitor osmotic dehydration kinetics for minimal solids uptake. *Journal of Food Engineering* 72(1): 85-91.

Mitcham, E.J. and R.E. McDonald (1992). Cell Wall Modification during Ripening ofKeitt'andTommy Atkins' Mango Fruit. *Journal of the American Society for Horticultural Science*, 117(6): 919-924.

Ponting, J., G. Watters, R. Forrey, R. Jackson and W. Stanley (1966). Osmotic dehydration of fruits. *Food Technology*, 20(10): 125-128.

Prasanna, V., T. Prabha and R. Tharanathan (2007). Fruit ripening phenomena–an overview. *Critical reviews in food science and nutrition,* 47(1): 1-19.

Raoult-Wack, A., S. Guilbert, M. Le Maguer and G. Rios (1991). Simultaneous water and solute transport in shrinking media. Part 1. Application to dewatering and impregnation soaking process analysis (osmotic dehydration). *Drying Technology,* 9(3): 589-612.

Rincon, A. and W.L. Kerr (2010). Influence of osmotic dehydration, ripeness and frozen storage on physicochemical properties of mango. *Journal of Food Processing and Preservation,* 34(5): 887-903.

Sagar, V.R. and P. Suresh Kumar (2009). Involvement of some process variables in mass transfer kinetics of osmotic dehydration of mango slices and storage stability. *Journal of Scientific and Industrial Research,* 68(12): 1043-1048.

Tedjo, W., K.A. Taiwo, M.N. Eshtiaghi and D. Knorr (2002). Comparison of pretreatment methods on water and solid diffusion kinetics of osmotically dehydrated mangos. *Journal of Food Engineering*, 53(2): 133-142.

Torezan, G.A.P., P.C.C. Favareto, D. Pallet and H.C. Menezes (2004). Osmotic dehydration of mango: effects of temperature and process time, *Drying 2004- Proceedings of the 14th International Drying Symposium* Sao Paulo, Brazil, pp. 2165-2172.

Torres, J.D., P. Talens, I. Escriche and A. Chiralt (2006). Influence of process conditions on mechanical properties of osmotically dehydrated mango. *Journal of Food Engineering,* 74(2): 240-246.

Yan, Z., M.J. Sousa-Gallagher and F.A.R. Oliveira (2008). Shrinkage and porosity of banana, pineapple and mango slices during air-drying. *Journal of Food Engineering,* 84(3): 430-440.

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