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Mass transport parameters during osmotic dehydration of cashew apple slices

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Abstract
Mass transfer kinetics during osmotic dehydration of cashew apple slices (Vengurla – 4) of thickness (5, 7.5 and 10 mm), sugar syrup concentration (40, 50 and 60ºB) and osmotic drying temperature (40, 50 and 60 ºC), solution: fruit ratio (10:1) at osmotic drying time 210 minutes were evaluated. For a fixed osmotic concentration as the temperature of the osmotic drying increases from 40 to 60 ^{0}C the water loss (%), solid gain (%) and mass reduction (%) increases in all the thickness of cashew apple slices for all the osmotic concentration respectively. For a particular osmotic temperature, as the osmotic concentration increases from 40 to 60 ^{0}B, the water loss, solid gain and mass reduction increases in all the thickness of cashew apple slices for all the osmotic temperature respectively.

Keywords: cashew apple slices, osmotic dehydration, water loss, solid gain, mass reduction

1. Introduction

India is the largest producer, processer, consumer and exporter of cashew in the world (Elakkiya *et al.*, 2017) [7]. Major states contributing to the cashew nut production in India are Maharashtra, Andhra Pradesh, Orissa and Kerala. Among the major states in the country, Maharashtra tops with respect to area, production and productivity of cashew nut (Nayak and Paled, 2018) [18]. Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth Dapoli, Maharashtra, has released and recommended the nine varieties of cashew i.e. Vengurla-1, Vengurla-2, Vengurla-3, Vengurla-4,Vengurla-5,Vengurla-6,Vengurla-7,Vengurla-8 and Vengurla-9, respectively (Bhuwad *et al.*, 2017) [5]. 'Vengurla-4' is one of the preferred variety by farmers of Konkan region because of larger size (> 7.5 g) of cashew nut and higher productivity. Cashew fruit comprises kidney shaped nut attached to the apple (cashew apple) which is technically a swollen peduncle. The cashew apple is about 6-7 times greater in weight than the raw nut. At present about 90-95% cashew apple is wasted, owing to its rapid perishable nature, lack of harvesting techniques, improper post harvest handling and non adoption of cashew processing technologies (Salvi *et al.*, 2016) [24].

Pre-drying treatment such as osmotic dehydration (OD) before conventional hot air drying reduces the energy consumption and improves food quality (Torreggiani 1993) [30] and (Sereno *et al.* 2001) [25]. Osmotic dehydration is used for partial dehydration of foods, usually as an upstream processing step, before they are subjected to further processing such as air drying (Fernandes *et al*., 2008) [9], (Azoubel *et al*., 2009) [4] and (Sosa *et al*., 2011) [29] to make the final product shelf stable).

The cashew apple generates high amount waste residues and the wastage rate exceeds about 90 – 95% of production in India. Economic and efficient methods for handling and processing could help facing this problem through processing and transformation into good quality attractive products with extended shelf life. The problems limiting the acceptability of cashew apple are its astringency, seasonability and poor storability. Osmotic dehydration is considered as an answer to these problems, where high quality ready-to-eat products with good shelf life can be produced. Several production factors such as sample size, nature and duration of osmotic treatment etc. affect the efficiency of osmotic dehydration (Mini and Archana, 2016) [16] and (Salve *et al.*, 2019) [23].

The objectives of the present work were to carry out the mass transfer parameters during osmotic dehydration of cashew apple (variety Vengurla -4) using sugar solution at varied concentration, cashew apple of varied thickness and to study the effect of temperature of the solution.

Materials and Methods

Fresh cashew apple fruits were sorted for uniform size, colour, physical damage and maturity. Fruits were washed with tap water to remove dirt and were wiped with muslin cloth to remove surface moisture. Fruits were cut to 5, 7.5 and 10 mm thick slices by SS knife. The sugar syrup of three concentrations (40, 50 and 60^0B) was prepared by dissolving sugar in distilled water using glass rod as stirrer. Concentration of sugar syrup was checked by using digital refractometer (Make: ATAGO, Model; RX-5000, Japan). Sugar was used as osmotic agent as it prevents food discolouration to a large extent and imparts good taste to the final product.

Experimental design for osmotic dehydration

In osmotic dehydration, a sample of cashew apple slices of 5, 7.5 and 10 mm thickness each weighing 50 g were prepared. Fruit slices: syrup ratio was maintained at1:10 (w/v). The glass beakers containing sugar syrup (40, 50 and 60^0B) were placed inside the constant temperature circulatory water bath at (40, 50 and 60 ^{0}C) and slices were put into the syrup after attainment of desired temperature. After 210 min of osmotic dehydration glass beaker was removed from the water bath and the cashew apple slices were taken out from the beaker and immediately rinsed with distilled water as per procedure (Mundada *et al*., 2011) [17] to remove the solute adhered to fruit surface. Then slices were spread on the tissue paper for 5 min to remove the surface moisture. The weight of osmotically dehydrated cashew apple slices was recorded. The slices were then put in the moisture boxes. The moisture boxes were kept in hot air oven at 105 ^{0}C ± 1 ^{0}C for 24 h for dry matter and moisture content determination. Each treatment replicated thrice and data was recorded.

Osmotic dehydration parameters

The fresh and osmotic dehydrated cashew apples were placed in an oven at 105 ^{0}C until constant weight to determine dry matter and moisture content. The parameters WL SG and MR were determined through the following equations (Correa, *et al*., 2010) [6]; (Shi *et al*., 1995) [26] and (Silva *et al*., 2012) [28].

$$WL = \frac{W_{W0} - W_W}{W_0} \quad .... (1)$$

$$SG = \frac{W_s - W_{s0}}{W_0}. \quad ... (2)$$

$$MR = \frac{W_0 - W_\theta}{W_0} \quad .... (3)$$

Where,

W_{W0}- the initial moisture content (kg of water/ kg of total weight)

W_W - the moisture content at time, t (kg of water/ kg of total weight)

W_0 - the initial weight of the sample, kg

W_s - the solid content at time, t (kg dry solids/kg total weight)

W_{s0} – the initial solid content of sample all in g (kg dry solid/kg of total weight)

W_θ= Mass of slices after time θ, kg

Results and Discussion

Water loss

The water loss was found 36.97 ± 0.28, 38.87 ± 0.34, and 41.91 ± 0.47 per cent for 40 ^{0}Brix; 39.51 ± 0.47, 43.74 ± 0.29, and 48.63 ± 0.45 per cent for 50 ^{0}Brix and 44.55 ± 0.41, 48.13 ± 0.20, and 52.04 ± 0.39 per cent for 60 ^{0}Brix osmotic concentration for 5 mm thick slices dried at 40 ^{0}C, 50 ^{0}C and 60 ^{0}C up to 210 minutes respectively. The water loss was found 33.38 ± 0.12, 36.86 ± 0.34, and 41.13 ± 0.34 per cent for 40 ^{0}Brix; 36.13 ± 0.21, 41.08 ± 0.13, and 45.21 ± 0.11 per cent for 50 ^{0}Brix and 40.09 ± 0.72, 44.00 ± 0.17, and 50.38 ± 0.15 per cent for 60 ^{0}Brix osmotic concentration dried at 40 ^{0}C, 50 ^{0}C and 60 ^{0}C for 7.5 mm thick slices. The water loss was found 30.53 ± 0.98, 34.96 ± 0.46, and 39.24 ± 0.92 per cent for 40 ^{0}Brix; 33.62 ± 0.36, 38.79 ± 0.41, and 42.03 ± 0.51 per cent for 50 ^{0}Brix and 36.66 ± 0.77, 41.77 ± 0.26, and 47.00 ± 0.25 per cent for 60 ^{0}Brix osmotic concentration dried at 40 ^{0}C, 50 ^{0}C and 60 ^{0}C for 10 mm thick slices.

Table 1 shows the ANOVA for the effect of osmotic concentration (^{0}B), effect of osmotic temperature (^{0}C) and interaction effect of both osmotic concentration and osmotic temperature on the water loss. It can be seen from the Table 1 that the effect of osmotic concentration, osmotic temperature and interaction effect of both osmotic concentration and osmotic temperature on the water loss was found significant ($p \leq 0.01$) for all the thickness. The results are in agreement with the results obtained for osmotic drying for sapota, guava, pineapple and apple slices by Kedarnath *et al*., (2014) [13]; Gaikwad *et al*., (2016) [10]; Zahoor and Khan (2017) [32] and Paradkar and Sahu (2018) [19] respectively. The increase of water loss (%) *w.r.t.* increase in osmotic concentration is due to the driving force for the mass transfer is provided by the higher osmotic pressure of the sucrose solutions reported by Azoubel and Murr (2003) [2]. The increase of water loss (%) w.r.t. increase in osmotic temperature is due to the higher process temperatures seem to promote faster water loss through swelling and plasticising of cell membranes reported by Lazarides *et al*., (1995) [15]. During osmotic treatment, when temperature increased then loss of water and uptake of solid took place reported by Alakali *et al.*, (2006) [1] and Rafiq Khan (2012) [21].

Solid Gain

The solid gain was found 5.23 ± 0.06, 5.87 ± 0.26, and 6.37 ± 0.09 per cent for 40 ^{0}Brix ; 5.57 ± 0.03, 6.06 ± 0.03, and 6.70 ± 0.33 per cent for 50 ^{0}Brix and 6.01 ± 0.11, 6.66 ± 0.16, and 7.91 ± 0.22 per cent for 60 ^{0}Brix osmotic concentration for 5 mm thick slice dried at 40 ^{0}C, 50 ^{0}C and 60 ^{0}C up to 210 minutes respectively. The solid gain was found 5.07 ± 0.17, 5.50 ± 0.03, and 5.90 ± 0.04 per cent for 40 ^{0}Brix; 5.33 ± 0.01, 5.72 ± 0.03, and 6.31 ± 0.05 per cent for 50 ^{0}Brix and 5.59 ± 0.06, 6.40 ± 0.07, and 7.53 ± 0.19 per cent for 60 ^{0}Brix osmotic concentration dried at 40 ^{0}C, 50 ^{0}C and 60 ^{0}C for 7.5 mm thick slices. The solid gain was found 4.59 ± 0.16, 4.96 ± 0.06, and 5.44 ± 0.15 per cent for 40 ^{0}Brix; 5.02 ± 0.06, 5.19 ± 0.04, and 5.77 ± 0.14 per cent for 50 ^{0}Brix and 5.26 ± 0.09, 5.64 ± 0.03, and 6.27 ± 0.09 per cent for 60 ^{0}Brix osmotic concentration dried at 40 ^{0}C, 50 ^{0}C and 60 ^{0}C for 10 mm thick slices.

Table 2 shows the effect of osmotic concentration and osmotic temperature on the solid gain was found significant ($p \leq 0.01$) for all the thickness. The interaction effect of osmotic concentration and osmotic temperature on the solid gain was found significant ($p \leq 0.01$) for 5 and 7.5 mm slice thickness and non-significant for 10 mm slice thickness of cashew apple.

The results are in agreement with the results obtained for osmotic drying of apple, acerola, papaya, guava and toddy fruit by Videv *et al*., (1990) [31]; Silva *et al*., (2010) [27]; Jain *et al*., (2011) [12]; Gaikwad *et al*., (2016) [10] and Khin and Thet (2016) [14] respectively. The increase of solid gain (%) *w.r.t.* increase in osmotic concentration is due to the increase in the osmotic pressure gradients reported by Ispir and Togrul (2009) [11]. Increased solution concentration resulted in the increase in the osmotic pressure gradients and higher water loss Azoubel and Murr (2004) [3] and Phisut (2012) [20]. The increase of solid gain (%) *w.r.t.* increase in osmotic temperature is due to the higher process temperatures seem to promote faster solid gain due to the membrane swelling and plasticizing effect reported by Rahman and Lamb (1990) [22].

Mass Reduction

The mass reduction was found 31.73 ± 0.31, 33.00 ± 0.60, and 35.53 ± 0.42 per cent for 40 ^{0}Brix ; 33.93 ± 0.50, 37.68 ± 0.29, and 41.93 ± 0.42 per cent for 50 ^{0}Brix and 38.53 ± 0.31, 41.47 ± 0.31, and 44.13 ±0.61 per cent for 60 ^{0}Brix for 5 mm thick slice dried at 40 ^{0}C, 50 ^{0}C and 60 ^{0}C up to 210 minutes respectively. The mass reduction was found 28.31± 0.12, 31.36± 0.31, and 35.13±0.31 per cent for 40 ^{0}Brix; 30.80± 0.20, 35.35± 0.15, and 38.90±0.10 per cent for 50 ^{0}Brix and 34.50 ± 0.10, 37.60± 0.20, and 42.85±0.13 per cent for 60 ^{0}Brix osmotic concentration dried at 40 ^{0}C, 50 ^{0}C and 60 ^{0}C for 7.5 mm thick slices. The mass reduction was found 25.93 ± 0.83, 30 ± 0.40, and 33.80 ± 1.05 per cent for 40 ^{0}Brix; 28.60 ± 0.40, 33.60± 0.40, and 36.27 ±0.64 per cent for 50 ^{0}Brix and 31.40 ± 0.72, 36.13± 0.23, and 40.73 ±0.23 per cent for 60 ^{0}Brix osmotic concentration dried at 40 ^{0}C, 50 ^{0}C and 60 ^{0}C for 10 mm thick slices.

Table 3 shows the effect of osmotic concentration and osmotic temperature on the solid gain was found significant ($p \le 0.01$) for all the thickness. The interaction effect of osmotic concentration and osmotic temperature on the solid gain was found significant ($p \le 0.01$) for 5 and 7.5 mm slice thickness and non-significant for 10 mm slice thickness of cashew apple.

The results are in agreement with the results obtained for cashew apple, guava, and apple slices by Falade *et al.*, (2003) [8]; Gaikwad *et al*., (2016) [10] and Paradkar and Sahu (2018) [19] respectively.

Table 1: ANOVA for the effect of Osmotic Concentration (^{0}B) and Osmotic Temperature (^{0}C) on the water loss (%) for cashew apple slices (5, 7.5 and 10 mm thick) at 210 minutes of osmosis.

Osmotic Concentration (^{0}B)	**Osmotic Temperature (^{0}C)**			**Mean**
	40 ^{0}C	**50 ^{0}C**	**60 ^{0}C**	
5 mm thick slices				
40 ^{0}B	36.97± 0.28	38.87 ± 0.34	41.91 ± 0.47	39.248
50 ^{0}B	39.51 ± 0.47	43.74 ± 0.29	48.63 ± 0.45	43.961
60 ^{0}B	44.55 ± 0.41	48.13 ± 0.20	52.04 ± 0.39	48.238
Mean	40.338	43.582	47.527	
SE_1(Osmotic Conc.)	0.126			
CD_1	0.378			
SE_2(Osmotic Temp.)	0.126			
CD_2	0.378			
SE interaction (Osmotic Conc.x Osmotic Temp.)	0.219			
CD interaction	0.654			
7.5 mm thick slices				
Osmotic Concentration (^{0}B)	**Osmotic Temperature (^{0}C)**			**Mean**
	40 ^{0}C	**50 ^{0}C**	**60 ^{0}C**	
40 ^{0}B	33.38 ± 0.12	36.86 ± 0.34	41.13 ± 0.34	37.124
50 ^{0}B	36.13 ± 0.21	41.08 ± 0.13	45.21 ± 0.11	40.807
60 ^{0}B	40.09 ± 0.12	44.00 ± 0.17	50.38 ± 0.15	44.826
Mean	36.537	40.647	45.573	
SE_1(Osmotic Conc.)	0.068			
CD_1	0.204			
SE_2(Osmotic Temp.)	0.068			
CD_2	0.204			
SE interaction (Osmotic Conc.x Osmotic Temp.)	0.118			
CD interaction	0.354			
10 mm thick slices				
Osmotic Concentration (^{0}B)	**Osmotic Temperature (^{0}C)**			**Mean**
	40 ^{0}C	**50 ^{0}C**	**60 ^{0}C**	
40 ^{0}B	30.53 ± 0.98	34.96 ± 0.46	39.24 ± 0.92	34.910
50 ^{0}B	33.62 ± 0.36	38.79± 0.41	42.03 ± 0.51	38.147
60 ^{0}B	36.66 ± 0.77	41.77± 0.26	47.00 ± 0.25	41.812
Mean	33.600	38.510	42.759	
SE_1(Osmotic Conc.)	0.202			
CD_1	0.606			
SE_2(Osmotic Temp.)	0.202			
CD_2	0.606			
SE interaction(Osmotic Conc.x Osmotic Temp.)	0.350			
CD interaction	1.049			

Table 2: ANOVA for the effect of Osmotic Concentration (^{0}B) and Osmotic Temperature (^{0}C) on the solid gain (%) for cashew apple slices (5, 7.5 and 10 mm thick) at 210 minutes of osmosis

Osmotic Concentration (^{0}B)	**Osmotic Temperature (^{0}C)**			**Mean**
	40 ^{0}C	**50 ^{0}C**	**60 ^{0}C**	
5 mm thick slices				
40 ^{0}B	5.23 ± 0.06	5.87 ± 0.26	6.37 ± 0.09	5.826
50 ^{0}B	5.57 ± 0.03	6.06 ±0.03	6.70 ± 0.33	6.112
60 ^{0}B	6.01 ± 0.11	6.66 ± 0.16	7.91 ± 0.22	6.860
Mean	5.604	6.200	6.993	
SE_1(Osmotic Conc.)	0.058			
CD_1	0.175			
SE_2(Osmotic Temp.)	0.058			
CD_2	0.175			
SE interaction (Osmotic Conc.x Osmotic Temp.)	0.101			
CD interaction	0.303			
7.5 mm thick slices				
Osmotic Concentration (^{0}B)	**Osmotic Temperature (^{0}C)**			**Mean**
	40 ^{0}C	**50 ^{0}C**	**60 ^{0}C**	
40 ^{0}B	5.07± 0.17	5.50 ± 0.03	5.90 ± 0.04	5.522
50 ^{0}B	5.33 ± 0.01	5.72 ± 0.03	6.31± 0.05	5.789
60 ^{0}B	5.59 ± 0.06	6.40 ± 0.07	7.53 ± 0.19	6.508
Mean	5.332	5.876	6.611	
SE_1(Osmotic Conc.)	0.026			
CD_1	0.078			
SE_2(Osmotic Temp.)	0.026			
CD_2	0.078			
SE interaction (Osmotic Conc.x Osmotic Temp.)	0.045			
CD interaction	0.136			
10 mm thick slices				
Osmotic Concentration (^{0}B)	**Osmotic Temperature (^{0}C)**			**Mean**
	40 ^{0}C	**50 ^{0}C**	**60 ^{0}C**	
40 ^{0}B	4.59 ± 0.16	4.96 ± 0.06	5.44 ± 0.15	4.998
50 ^{0}B	5.02 ± 0.06	5.19 ± 0.04	5.77 ± 0.14	5.323
60 ^{0}B	5.26 ± 0.09	5.64 ± 0.03	6.27 ± 0.09	5.723
Mean	4.956	5.266	5.823	
SE_1(Osmotic Conc.)	0.034			
CD_1	0.102			
SE_2(Osmotic Temp.)	0.034			
CD_2	0.102			
SE interaction(Osmotic Conc.x Osmotic Temp.)	0.059			
CD interaction	NS			

Table 3: ANOVA for the effect of Osmotic Concentration (^{0}B) and Osmotic Temperature (^{0}C) on the mass reduction (%) for cashew apple slices (5, 7.5 and 10 mm thick) at 210 minutes of osmosis

Osmotic Concentration (^{0}B)	**Osmotic Temperature (^{0}C)**			**Mean**
	40 ^{0}C	**50 ^{0}C**	**60 ^{0}C**	
5 mm thick slices				
40 ^{0}B	31.73 ± 0.31	33.00 ± 0.60	35.53 ± 0.42	33.422
50 ^{0}B	33.93 ± 0.50	37.68 ± 0.29	41.93 ± 0.42	37.849
60 ^{0}B	38.53 ± 0.31	41.47 ± 0.31	44.13 ± 0.61	41.378
Mean	34.733	37.382	40.533	
SE_1(Osmotic Conc.)	0.145			
CD_1	0.433			
SE_2 (Osmotic Temp.)	0.145			
CD_2	0.433			
SE interaction (Osmotic Conc.x Osmotic Temp.)	0.251			
CD interaction	0.751			
7.5 mm thick slices				
Osmotic Concentration (^{0}B)	**Osmotic Temperature (^{0}C)**			**Mean**
	40 ^{0}C	**50 ^{0}C**	**60 ^{0}C**	
40 ^{0}B	28.31 ± 0.12	31.36 ± 0.31	35.13 ± 0.31	31.602
50 ^{0}B	30.80 ± 0.20	35.35 ± 0.15	38.90 ± 0.10	35.018
60 ^{0}B	34.50 ± 0.10	37.60 ± 0.20	42.85 ± 0.13	38.318
Mean	31.204	34.771	38.962	
SE_1(Osmotic Conc.)	0.065			
CD_1	0.196			
SE_2 (Osmotic Temp.)	0.065			

CD_2	0.196			
SE interaction (Osmotic Conc.x Osmotic Temp.)	0.113			
CD interaction	0.339			
10 mm thick slices				
Osmotic Concentration (^{0}B)	**Osmotic Temperature (^{0}C)**			**Mean**
	40 ^{0}C	**50 ^{0}C**	**60 ^{0}C**	
40 ^{0}B	25.93 ± 0.83	30.00 ± 0.40	33.80 ± 1.05	29.911
50 ^{0}B	28.60 ± 0.40	33.60 ± 0.40	36.27 ± 0.64	32.822
60 ^{0}B	31.40 ± 0.72	36.13 ± 0.23	40.73 ± 0.23	36.089
Mean	28.644	33.244	36.933	
SE_1(Osmotic Conc.)	0.203			
CD_1	0.607			
SE_2 (Osmotic Temp.)	0.203			
CD_2	0.607			
SE interaction (Osmotic Conc.x Osmotic Temp.)	0.351			
CD interaction	NS			

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