Mechanical and osmotic dehydration behavior of pineapple and retention of vitamin C

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ARTICLE INFORMATION

ABSTRACT

The study was designed to observe the behavior of mechanical and osmotic dehydration of pineapple, retention of vitamin C content during drying and development of jam from fresh and dehydrated pineapple. Osmotic dehydration carried out with pineapples collected from local market of Mymensingh in July 2015 and found that pineapples contained higher moisture content (93.9%,wb) than normal (85-87%,wb) and showed contradictory osmotic behavior due to higher moisture content and hormonal effect. Then the studies were conducted using pineapples of Gaint Kew variety collected from Madhupur without hormone treatment which contained 86.11% moisture, 0.36% ash, 13.89% total solid, 0.54% protein and 17.38 mg 100g^{-1} vitamin C. The osmotic concentration behavior was investigated using sugar and combined sugar-salt solution for 6mm thick pineapple slices and immersion time was 6 h. The extent of water loss, solid gain and normalized solid content were strongly influenced by strength of osmotic solution. It was found that K-value (mass transfer coefficient) increases with increasing concentration and was the highest (0.15 min^{-1}) for 55/5% sugar/salt solution and lowest (0.07 min^{-1}) for 45% sugar solution. Three different temperatures (55, 60 and 65 °C) and thicknesses (4, 6 and 8 mm) were used to investigate the drying behavior of pineapple slices in a mechanical dryer. Activation energy value of 8.14 Kcal g-mole^{-1} was found for fresh pineapple slices. 55/5% sugar/salt osmosed and dried pineapple gave 5.46 times higher dryer throughput compared to nonosmosed dried pineapple. Degradation of vitamin C content of pineapple at different air-dry bulb temperatures (55, 60 and 65 °C) of 6 mm thickness was investigated and activation energy for degradation of vitamin C was found to be 14.38 Kcal g-mole^{-1}. Osmotic dehydration prior to air drying, gave the lower rate of degradation of vitamin C during drying compared to that dried without osmosis. Developed jams were tested for their acceptability by sensory evaluation using 1-9 point hedonic scale and jam made from osmotically dehydrated (55/5% sugar-salt and then dried at 60 °C) secured highest score (8.5) and ranked as 'like very much', while the other products were ranked as 'like moderately'.

Keywords: Dehydration, osmosis, activation energy, vitamin C, jam

1 Introduction

Pineapple (*Ananas comosus*), a member of Bromeliaceae family, is one of the most favorite non-citrus tropical and subtropical fruit, due to its attractive flavor, refreshing sugar-acid balance and its high vitamin C and organic acids contents (Bartolomé et al., 1995). The pineapple contains protein, carbohydrate, water soluble vitamins such as B, C, iron, calcium, carotene etc. The fruit acts like a digestive as well as a natural anti-inflammatory fruit. Bromelain is present in fresh pineapples which reduced the swelling as associated with in the inflammatory conditions like gout, arthritis, sore throat and acute sinusitis. The recovery time for surgeries and injuries is also reduced. Pineapple fiber is found to be more delicate in texture when compared to any other vegetable fiber. The vitamin C content of pineapple is quite high, 24 mg $100g^{-1}$ (Joy, 2010).

From a nutritional point of view, vitamin C is vital importance to develop and maintain of human body. Recent scientific evidence indicates that an increased intake of vitamin C is associated with a reduced risk of chronic diseases such as cancer, cardiovascular diseases, cataracts, probably through antioxidant mechanisms. Thus, vitamin C must be obtained through the diet. Deficiency of vitamin C leads to scurvy which can be prevented with only 10 mg vitamin C per day, an amount easily obtained through diet.

As the availability of pineapple is very high in harvesting season, a considerable amount is spoiled every year due to their high moisture content and virtually out of market during off season due to lack of proper preservation methods. The best way of preservation fruits is drying or dehydration as other methods are not cost effective and require sophisticated technology including costly machineries. Drying or dehydration refers to the removal of moisture from food material so that an unfavorable environment is created for microorganisms responsible for spoilage. Since the dehydrated products would be acceptable as food only if it retains a good color, flavor, texture and nutritive value upon rehydration, the conditions of drying and reconstitution procedures must be carefully chosen to preserve these qualities as much as possible. However, during processing, especially with the application of heat, vitamins decreased and drying of fruits like pineapple may lead to loss of the vitamin C (Osundahunsi, 2008). One way to prevent loss of vitamins during air dehydration of fruit, pretreatment of fruit slices with sucrose-osmosis (i.e. osmotic dehydration) has been proved effective (Alvarez et al., 1995; Karim, 2005).

Fruit and vegetables can be partially dehydrated by immersion in hypertonic (osmotic) solution. Since this solution has high osmotic pressure and consequently low water activity, a driving force for water removal arises between solution and food, and the natural cell walls acts as semi-permeable membranes (Lerici et al., 1985). However, perfect semi permeable membrane may not always be present in the raw materials undergoing osmosis, thus a two-way diffusion takes place and in general the process is termed as osmotic dehydration (Islam, 1990). Osmotic dehydration has been proposed for the production of intermediate moisture foods leading to intermediate products and for making ready-to-eat processed fruits (Ponting, 1966; Moy et al., 1978; Ramanuja and Jayaraman, 1980). From a technological point of view, direct osmosis can reduce processing time thus saving energy besides enhancing the organoleptic characteristics of dehydrated products. It is, therefore, an interesting method of utilizing tropical fruits and is suitable for on-site processing of tropical produce (Girod et al., 1990). Particularly as a pretreatment to develop engineered product, an important method of processing and preservation of pineapple is production of jam. Fruit jams are very nutritive and delicious products which are very well liked throughout the world and becoming an important part of our daily diet. It may be homemade or manufactured industrially. Commercial production of fruit jams is subject to standard formulations of fruit type, sugar content, adjusted acidity and pectin content.

The specific objectives of this study are (i) to analyze kinetics of air drying and osmotic dehydration of pineapple slices, (ii) to analyze chemical composition of pineapple and kinetics of vitamin C degradation, and (iii) to assess the sensory quality of the processed jam from fresh and dehydrated pineapple.

2 Materials and Methods

This study was conducted in the laboratories of the Department of Food Technology and Rural Industries under the Faculty of Agricultural Engineering and Technology, Bangladesh Agricultural University, Mymensingh. Pineapples were collected from Madhupur (Gaint Kew variety). The other materials such as salt, sugar, chemicals were provided from the laboratory stock.

2.1 Drying methods

Studies on dehydration of pineapple slices were performed as per the following methods: (i) osmotic dehydration as pretreatment, and (ii) mechanical drying.

2.1.1 Osmotic dehydration pretreatment

Pineapple of both varieties were washed and sliced into 4 mm, 6 mm and 8 mm thickness by a slicer. Sugar solution and combined sugar-salt solution of different concentrations were prepared and certain amount of sliced pineapple (with predetermined

moisture content) were immersed into each solution at room temperature for different periods of time. After the end of the each definite time interval, the slices were removed by gently blotting with tissue paper. The ratio of solution to pineapple slices was 10:1 (*w/w*). After weighing the slice at definite time interval, moisture content of each individual was determined by oven drying method. From the weight loss due to osmotic dehydration of each sample, percentage of water loss (%WL), solid gain (%SG), total solid (TS), and normalized solid content (NSC) were determined according to the standard formula as per Hawkes and Flink (1978).

2.1.2 Mechanical drying

In this method, cabinet dryer (Model OV-165, Gallen Kamp Company) was used for the dehydration of fresh and osmotically dehydrated pineapple slices. The dryer consists of several chambers in which trays of samples could be placed. The samples were dried by hot air supplied by a fan which was blowing air through a thermostatically controlled heater. The air velocity was recorded 0.6 m s^{-1} by an anemometer. Fresh pineapples were sliced into different thicknesses such as 4 mm, 6 mm, and 8 mm to determine the effect of thickness on drying time. Osmotically dehydrated slices and fresh slices of desired thicknesses were placed in trays in single layer and drying commenced at constant velocity and a specific air-dry bulb temperature. Again, to determine the effect of temperature samples of constant thickness were dried at different temperature such as 55 °C, 60 °C, and 65 °C at constant air velocity (0.6 m s^{-1}). The extent of drying was determined mathematically from known initial moisture content. Both of fresh and pretreated samples were dried until it came to the equilibrium condition or to desired moisture content like 14.67% (*wb*).

2.2 Chemical analysis

Moisture content, ash content, vitamin C and sugar was determined adopting the method of (Ranganna, 2012). The pH of the pineapples was measured by using pH meter (Potentiometer) at an ambient temperature. The pH meter was first standardized using buffer of pH 7.00.

Acidity Twenty five grams (25 g) sample were homogenized in a blender with distilled water. The blended material upon being filtered was transferred to a 250 mL volumetric flask and the volume was made up to the mark with distilled water. 5 mL of this solution was taken in a conical flask and titrated with 0.1N NaOH solution just below the end point, using phenolphthalein indicator. The titration was

done for several times for accuracy. Percent titrable acidity was calculated as per following formula:

$$\%TA = \frac{T \times N \times V_1 \times E}{V_2 \times W \times 1000} \times 100 \qquad (1)$$

where $\%TA$ = percent titrable acidity, T = titre, N = normality of NaOH, V_1 = volume made up, E = equivalent weight of acid, V_2 = volume of sample taken for estimation, W = weight of sample.

Protein Protein was determined by Micro-Kjeldahl method described by AOAC (2005).

2.3 Product development

2.3.1 Basic formulation of jam

Jam is defined as a semisolid food made from not less than 45% (weight basis) fruit and 55% (weight basis) sugar (Desrosier and Desrosier, 1978). This substrate is concentrated to 65% or above soluble solids. Pectin and acid was added to overcome the deficiencies that occur in the fruit itself. Standard formulations are developed according to their end use, consumer preferences, market demand, food laws, buyer's specifications and economic utilization of inputs required.

Table 1. Formulation of pineapple jams

Ingredients	Sample code		
	505	606	707
Pineapple pulp (%)	45	45	45
Sugar (%)	55	39.6	45
Citric acid (%)	0.6	0.6	0.6
Pectin (%)	1.0	1.0	1.0

Here, 505 =jam made from fresh pineapple pulp, 606 = jam made from pineapple pulp osmosed by 55/5% sugar/salt solution then dried and 707= jam made from mechanically dried pineapple pulp.

2.3.2 Formulation of pineapple jam

Three samples (fresh, mechanically dried and osmosed dried) pineapple slices were selected for making jams for organoleptic evaluation.

2.3.3 Processing of jam

Extraction of pulp Three samples (Fresh, Mechanically dried and osmosed dried) pineapple slices were used for extraction of pulp. The pulp was blended in an electric blender. After proper blending, the pulp was pasteurized at a temperature of 75 °C for two minutes. The pasteurized pulp was stored in a deep freeze at a temperature of −20 °C for future use.

Preparation of jam   Jam is a product made by boiling fruit pulp with sufficient sugar to a reasonably thick consistency, firm enough to hold the fruit tissues in position. The calculation for various ingredients for the jam incorporated with thickening agents were first. A general procedure was followed to prepare pineapple jam. Sugar and pulp were weighed according to the formulation and heated to boiling and allowed to boil for 5-10 min. Citric acid dissolved in water was added at this stage. According to formulation given in Table 1, pectin and sugar was mixed with each other and added to the cooking pot. The mixture was allowed to boil for further 5 minutes to ensure complete dissolution of pectin. Soluble solids were determined before pouring the hot jams in to desired glass jars. The glass jars were kept for cooling in room temperature for overnight. The surface of the jam was covered with melted wax (paraffin) that solidified on cooling thus sealing the surface. The processed products were then storage at ambient temperature (in cool and dry place).

2.3.4   Sensory evaluation

The consumer acceptability of developed products was evaluated by a taste-testing panel. The 1-9 point hedonic scale was used to determine this acceptability. The panelists were selected from among the teachers and students of the department of Food Technology and Rural industries, Bangladesh Agricultural University, Mymensingh. Samples were served to the trained panelists (10) and were asked to assign appropriate score for characteristic color, flavor, texture and overall acceptability of biscuit. The scale was arranged such that: 9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like nor dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much, and 1 = dislike extremely.

3   Results and Discussion

3.1   Osmotic dehydration

Osmotic dehydration carried out with pineapple using sugar and combined sugar-salt solution. The solution to sample ratio was 10:1 and sample thickness was 6 mm. Several authors (Islam, 1980; Moy et al., 1978) indicated that 4 and 8 h osmotic time might be regarded as optimum time. It was, therefore, decided that minimum osmosis time would be 6 h.

3.1.1   Effect of moisture content and hormone on osmosis concentration

Osmotic dehydration was conducted with pineapples collected from local market of Mymensingh in July. Determined moisture content of the pineap-ples showed substantially higher moisture content (as high as 93.9) than normal pineapple reported in the literature (85-87%). While investigating the effect of solution type and concentration on mass transfer parameters such as NSC (normalized solid content), %WL (percent water loss) and %SG (percent sugar content), it was found that normal osmotic concentration behavior could not be demonstrated even after 5 min or 10 min immersion time. It was seen that just after immersion time the %WL was from 84.35 and 86.6% for 60% sugar and 60/5% sugar/salt solution osmosed pineapple respectively, while the corresponding %SG values were 78.9 and 78.1 and the NSC values were 10.48 and 15.13. After initial period (5 or 10 minutes), the NSC values decreased with time (as seen in the Table 2) and the determined k-values were negative. This behavior is in contrast to the normal osmotic concentration behavior as after initial rapid period, %WL, %SG and NSC increases with time. Moreover, NSC varies as $\sqrt{t}$ (where t = time, $\sqrt{t}$ = square root of time), following unsteady state diffusion equation with positive k-values (Islam, 1980). Thus it was of interest to conduct further studies with pineapple having lower initial moisture content and the farmers at Madhupur were contacted and upon discussion it is concluded that pineapples treated with growth hormone, particularly in the rainy season, contained high moisture content such as above 90%. Finally initial moisture content of pineapple is shown to effect osmotic concentration behavior as NSC, %WL and %SG increased with increasing initial moisture content (**??**). The studies conducted with the pineapples were collected from Madhupur in August ensuring that these were not treated with hormone.

3.1.2   Chemical composition of fresh pineapple

The fresh organic (without hormone) pineapple that were analyzed for composition found to contain moisture content 86.11%, total solid 13.89%, ash 0.36%, protein 0.54%, titratable acidity 0.67%, pH 3.52, total soluble solid 12%, vitamin C 14.38 mg $100g^{-1}$, total sugar 9.88%, reducing sugar 3.04% and non-reducing sugar 6.84%. The results of the present study showed a slight variation with the results of some other workers. Hemalatha and Anbuselvi (2013) found the chemical constituents of pineapple as moisture 87.3%, ash content 1.8 mg $100g^{-1}$, total soluble solids 13.3%, crude fiber 0.41 g 100g FW^{-1}, total sugars 8.66%, reducing sugars 10.5%, non-reducing sugars 7.4%, titratable acidity 2.03%, ascorbic acid 21.5 mg $100g^{-1}$.

3.1.3   Effect of sugar solution and time on mass transfer parameters

Effect of solution (sugar) on %WL and %SG   From Fig. 1a it is seen that for 45%, 55% and 60%, sugar solutions, %WL increases as the time increases and the
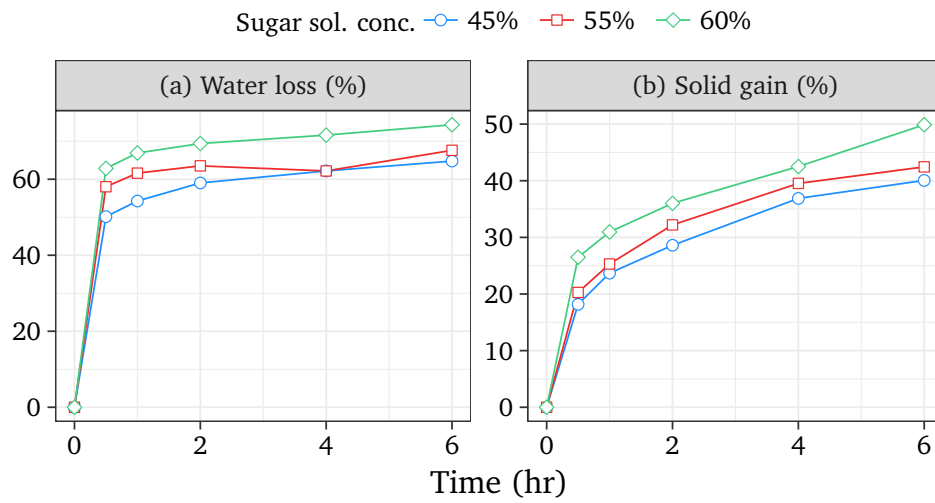
Figure 1. Temporal variation of (a) water loss, and (b) solid gain of 6 mm pineapple slices as affected by sugar solution of different concentrations
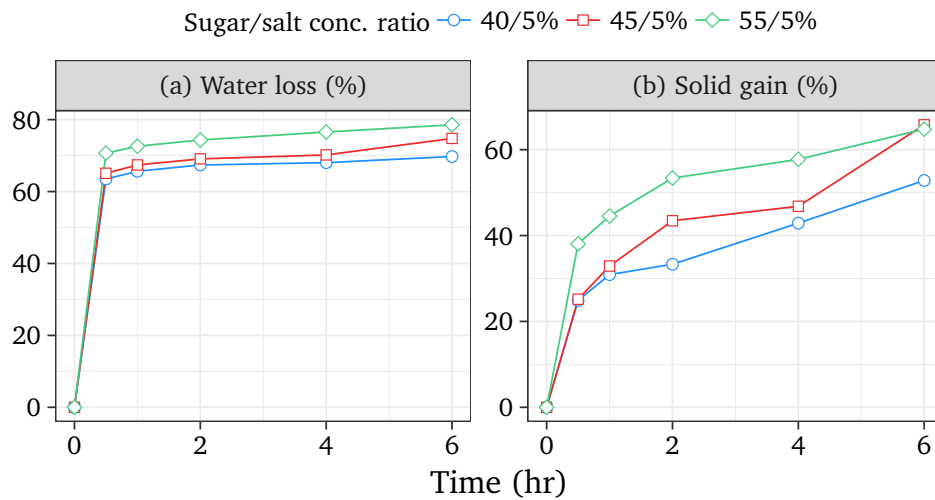

Figure 2. Temporal variation of (a) water loss, and (b) solid gain of 6 mm pineapple slices as affected by solution of different sugar/salt concentration ratio
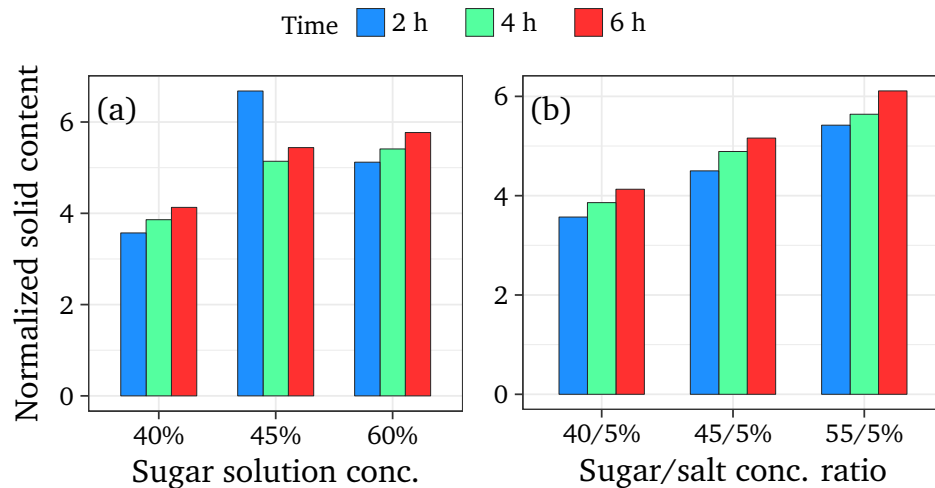

Figure 3. Temporal variation of normalized solid content (NSC) of pineapple as affected by different (a) sugar solution concentrations, and (b) sugar/salt concentration ratio

Table 2. 60% sugar concentration and 60/5% sugar/salt concentration, thickness 6 mm (1:10) at room temperature

Time (h)	Initial MC(%)	% Water loss (WL)	% Solid gain (SG)	NSC
60% sugar				
10		86.6	78.06	15.13
20	93.93	85.55	75.83	14.94
30		83.47	68.85	14.44
60		84.37	65.75	14.52
60/5% sugar/salt				
5		84.35	78.86	10.48
10		83.32	75.24	10.33
15	91.14	82.88	74.39	10.27
30		81.59	68.84	10.05
60		81.03	65.38	9.91

Table 3. Comparison of osmotic dehydration effect due to variation of moisture content of pineapple

Initial MC (%)	Solution concentration	Time (min)	%Water loss (WL)	%Solid gain (SG)	NSC
93.9	60% sugar	60	84.37	65.75	14.5
86.11			66.91	30.96	3.35
91.14	45/5% sugar/salt	60	75.68	48.47	9.17
86.64			67.99	32.9	4.27
93.9	55% sugar	60	81.98	47.38	13.45
86.11			61.6	25.3	4.45
93.9	45% sugar	60	81.98	54.88	13.64
86.11			54.27	23.68	3.35

rate of increase was rapid at the beginning period (0.5 h) and highest %WL was observed at 6 h immersion time. It is also seen from Fig. 1a that in case of %WL, 60% sugar solution gave the highest %WL (74.33) at 6 h of immersion time, whereas the lowest %WL (64.78) at 6 h was found for 45% sugar solution. Again, from Fig. 1b, among the three solutions, 60% sugar solution gave the highest solid gain at each time interval. It is also seen that for a given immersion time, %WL and %SG increases with increase in sucrose concentration and 60% sugar solution gave highest %SG (49.88), for a immersion time of 6 h while 45% sugar solution gave the lowest %SG (40.06) for similar immersion time (6 h) as determined according to the method of Hawkes and Flink (1978). Islam (1990) reported osmotic dehydration of mango in 60% sugar solution for 6 h to result in 58.64% WL and 5.9% SG.

Effect of solution (sugar/salt) on %WL and %SG
To depict the effect of solution concentration on %WL and %SG another figures were drawn using 40/5, 45/5 and 55/5 sugar-salt solution. From Fig. 2a and Fig. 2b it is seen that as percent sugar-salt concentration increases at constant solutes concentration, both %WL and %SG increase. In the case of %WL, 55/5% sugar /salt solution gave the highest value for a specific immersion time (78.56 at 6 h) and 40/5% sugar salt solution gave the lowest value (69.75 at 6 h) which similar to 60% sugar osmosed pineapple. Again from Fig. 2b it is seen that highest value %SG (64.79) was found for 55/5% sucrose/salt solution at 6 h of immersion time .On the other hand %SG for 40/5% sugar/salt solution was the lowest (52.83 for 6 h). From the above discussion, it is seen that %WL and %SG value was quite high compared with literature value such as Islam (1990) found 66.10% WL and 7.3% SG at 4.5 h of immersion time for tomato.

Effect of solution concentration and time on NSC
To observe the effect of solution concentration on NSC, experiments were conducted with 60%, 55%, 45% sugar solution and 55/5%,45/5%,40/5% sugar/salt solution for a period of 2, 4, and 6 h for 6 mm thick pineapple slices. The data were analyzed as per method of Hawkes and Flink (1978) and the calculated data are plotted in the Fig. 3a and Fig. 3b. The following equations developed from the calculated data by regression analysis as shown in Fig. 3a and Fig. 3b.

For sugar solution:

$$NSC = 0.091x + 0.471 \qquad (6\ h) \qquad (2)$$

$$NSC = 0.083x + 0.378 \qquad (4\ h) \qquad (3)$$

$$NSC = 0.078x + 0.318 \qquad (2\ h) \qquad (4)$$

For sugar/salt solution:

$$NSC = 0.99x + 3.153 \qquad (6\ h) \qquad (5)$$

$$NSC = 0.925x + 3.016 \qquad (4\ h) \qquad (6)$$

$$NSC = 0.89x + 2.464 \qquad (2\ h) \qquad (7)$$

From the above equations (Equation 2–7), Fig. 3 it is clearly seen that for sugar and sugar/salt solution, NSC of the osmosed product increases as solution concentration increases for a constant immersion time. These results indicate that at a higher solution concentration, faster water loss could be achieved and a much greater solids gain is observed by Azoubel and Murr (2004). It is also seen that for sugar solution, product osmosed at 60% solution for 6 h gives the highest NSC (5.77), while the lowest NSC (3.57) is obtained in product osmosed in 45% solution for 2 h. Sugar/salt solution also gives the similar result as shown in Fig. 3b, but giving somewhat higher NSC. Here, product osmosed at 55/5% solution for 6 h gives the highest NSC (6.11), while the lowest NSC (3.93) obtained in product osmosed in 40/5% sugar/salt solution for 2 h.

Kinetics of osmotic dehydration In order to analyze osmotic dehydration kinetics as per Fick's equation, NSC values of sugar/salt solution for 55/5%, 45/5%, and 40/5% and sugar solution 60%, 55% and 45% solutions were plotted as in (Fig. 4) and the data were fitted by regression analysis and regression lines are drawn. The regression equations for different salt solution are given below:

For sugar/salt solution:

$$NSC = 0.084\sqrt{t} + 2.683 \qquad (40/5\%) \qquad (8)$$

$$NSC = 0.096\sqrt{t} + 2.775 \qquad (45/5\%) \qquad (9)$$

$$NSC = 0.151\sqrt{t} + 4.151 \qquad (55/5\%) \qquad (10)$$

For sugar solution:

$$NSC = 0.075\sqrt{t} + 2.709 \qquad (45\%) \qquad (11)$$

$$NSC = 0.077\sqrt{t} + 3.176 \qquad (55\%) \qquad (12)$$

$$NSC = 0.109\sqrt{t} + 4.556 \qquad (60\%) \qquad (13)$$

where, t= time in min. From the above equation (Equation 8–13) NSC values for given solution concentration can be calculated for desired immersion time as NSC increases with square root of immersion time. By comparing the regression lines (Fig. 4a) and equations it can be clearly understood that k value increases with increasing concentration and is the highest (0.151) for 55/5% sugar/salt solution and lowest (0.084) for 40/5% sugar/salt solution. Again, from Fig. 4b, the highest k value (0.109) is found for 60% sugar solution and the lowest (0.075) is for 45% sugar solution. This indicates that increased concentration gives increased resistance to water and solute transfer due to higher solution viscosity.

Comparison between sugar and sugar/salt combination osmotic dehydration The results showed that for total similar solution concentration, 60% sugar solution gave higher NSC, %WL and %SG than 40/5% and 45/5% sugar/salt solution but gave lower NSC, %WL and %SG than 55/5% sugar/salt solution. 60% sugar osmosed sample for 6 h gave 74.33% WL, 49.88% SG and 5.77 NSC and 55/5% sugar/salt sample osmosed for 6 h gave 78.56% WL, 64.79% SG and 6.11 NSC. These results are similar to those reported by Uddin (2001) for papaya who found 55/5% sugar/salt solution to be more effective compared to other concentration of 60% sugar solution and contrary to that reported by Islam (1980) who found 45/15% sugar/salt solution to be the most effective one. These differences in effectiveness may be attributed to difference in product characteristics.

3.2 Mechanical drying

In mechanical drying under controlled conditions effects of thickness (4, 6 and 8 mm thick) of pineapple slices on drying time were observed when temperature, air velocity and other conditions were constant. In another experiment, 6 mm thick pineapple slices were dried at three different air dry bulb temperatures such as 55 °C, 60 °C and 65 °C to determine the effect of temperature on drying behavior of pineapple slices.

3.2.1 Effect of thickness dependent on drying

To observe the influence of thickness on drying time and consequently on rate constant 4 mm, 6 mm and 8 mm fresh pineapple slices were dried in a mechanical dryer at constant dry bulb temperature of 60 °C. The results was analyzed and then plotting the moisture ratio (MR) versus drying time (h) on semi-log paper plotting subsequently regression lines were drawn (Fig. 5a) and three different thicknesses of samples, the following regression equations were developed.

$$MR = 0.926e^{-0.31t} \qquad (4\ mm) \qquad (14)$$

$$MR = 0.947e^{-0.28t} \qquad (6\ mm) \qquad (15)$$

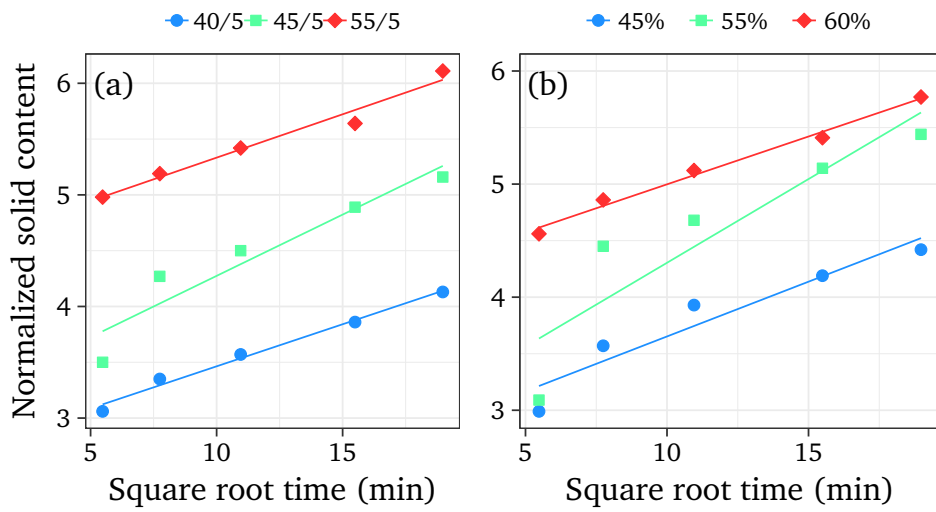$$MR = 0.948e^{-0.19t} \qquad (8\ mm) \qquad (16)$$

Figure 4. Effect of square root of time on normalized solid content for different (a) sugar/salt, and (b) sugar solutions
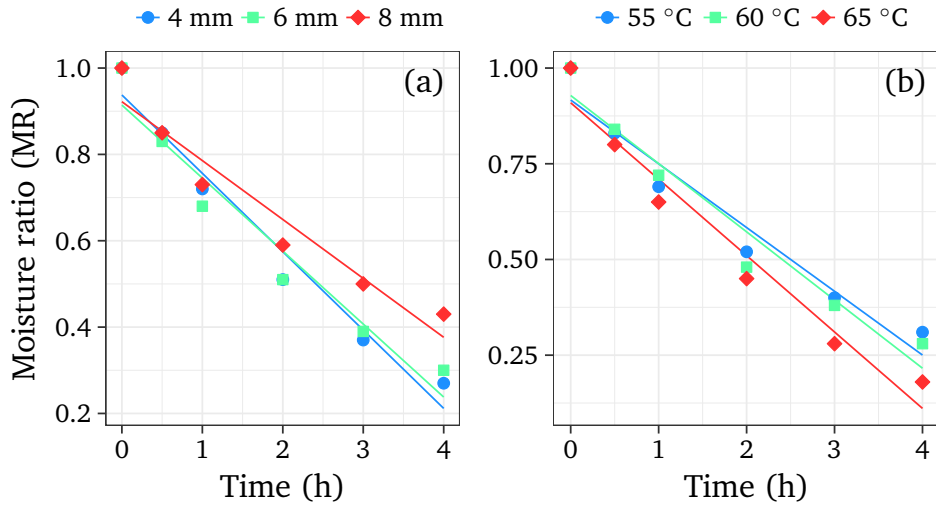

Figure 5. (a) Effect of slice thickness of pineapple slices under mechanical drying at 60 °C, and (b) effect of temperature on drying time for 6 mm pineapple slice in mechanical drying
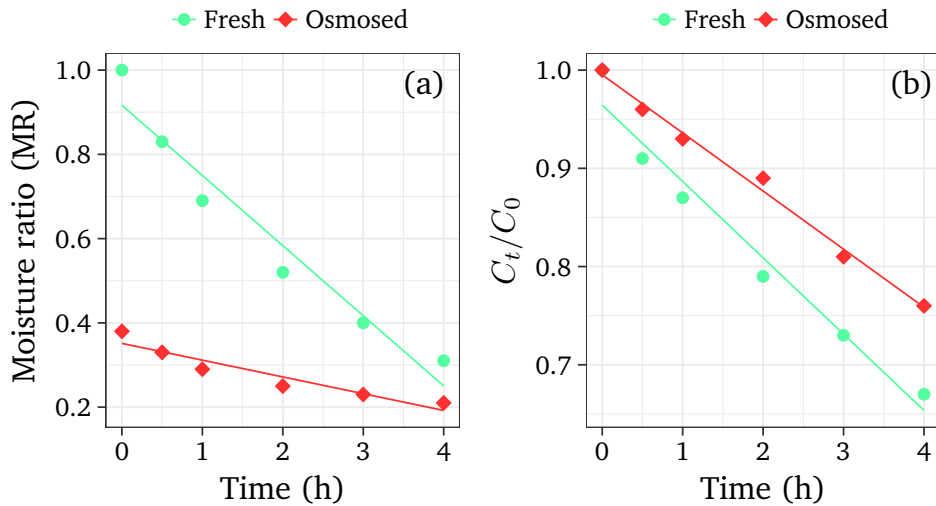

Figure 6. Effect of osmosis on (a) drying time, and (b) vitamin C content of pineapple slices

where, t = time in min. From Fig. 5a, it is observed that for a specific moisture ratio 4 mm pineapple slices require the lowest time, followed by 6 mm thick slices while 8 mm thick slices require the highest drying time. It can be said that when sample thickness increases, drying time increases while drying rate constant decreases.

The relationship between drying rate constant and sample thickness was developed by utilizing power law equation. Accordingly, drying rate constant for a given sample thickness was plotted on log ˘log scale (not shown in figure) and regression line drawn as per the following power-law equation:

$$m = 0.0141^{-0.69} \qquad (17)$$

where, m = drying rate constant, and l = sample thickness. From the above equation, it can be seen that the value of index n of the power law equation is 0.69 instead of 2 as predicted. It indicates that internal resistance to mass transfer is almost negligible compared to external resistance to mass transfer. This means that higher air flow rates would give higher rates of moisture removal. Lower n value such as 0.66 found using similar airflow rate (0.6 m s^{-1}) by Islam (1997).

3.2.2 Influence of temperature on drying time

To investigate the influence of temperature on drying time, 6 mm thick pineapple slices dried in a mechanical drier at three different air-dry bulb temperatures (55 °C, 60 °C and 65 °C). The plots of moisture ratio verses drying time were made on semi-log graph paper (Fig. 5b) subsequently the following regression equations were developed.

$$MR = 0.957e^{-0.28t} \qquad (55 °C) \qquad (18)$$
$$MR = 0.959e^{-0.31t} \qquad (60 °C) \qquad (19)$$
$$MR = 1.003e^{-0.42t} \qquad (65 °C) \qquad (20)$$

where, t = time in h. From Fig. 5b and above equations (Equation 18–20), it is clear that when temperature is increased, drying rate constant also increased. The drying rate may initially increases at very high temperature, but ultimately it may induce case hardening (Okos et al., 1992) with reduced drying rate and product quality due to cooking instead of drying. Thus selection of optimum temperature for drying is of significance during mechanical drying of any food product (Islam, 1980).

In order to determine activation energy for diffusion of water from pineapple the diffusion coefficients were calculated from the drying rate constants from regression lines (Fig. 7a). By plotting diffusion coefficient (De) versus inverse absolute temperature (1 Tabs^{-1}) in a semi-log scale a regression line was drawn (Fig. 7a) and the activation energy for diffusion of water from pineapple slices was calculated

and found to be 8.14 Kcal g-mole^{-1}. This calculated activation energy is quite similar to those reported by a number of researchers. Saravacos and Charm (1962) found 12 kcal g-mole^{-1} for potato and (Islam, 1980) found 7.7 Kcal g-mole^{-1} of activation energy for diffusion of water from potato while Uddin and Islam (1985) found 8.4 Kcal g-mole^{-1} for pineapple.

3.3 Effect of osmosis on drying time

For the determination of influence of osmosis on drying time, 6 mm thick pineapple slices of 55/5% sugar/salt solution was dried at constant dry bulb temperature (60 °C) in a cabinet dryer after 6 h osmosis. The moisture ratio (MR) versus time was plotted in a semi-log scale (Fig. 6a) and following regression equations were developed.

$$MR = 0.957e^{-0.28t} \qquad (fresh) \qquad (21)$$
$$MR = 0.353e^{-0.14t} \qquad (55/5\% \text{ osmosed}) \qquad (22)$$

where, t = time in h. From Fig. 6a and above equations it is seen that the drying time for fresh and 55/5% sugar/salt osmosed pineapple was 8.067 h and 9.01 h respectively. Thus it is seen that osmosed product takes somewhat more time to dry to moisture ratio 0.1, which is generally considered as the end of first falling rate period or end of thin layer drying at commercial level. However, considering the higher solid content with which the osmosed product enters the dryer i.e. 6.11 times (NSC = 6.11), it can be shown that 55/5% sugar-salt product gives (8.067/9.016 × 6.11) 5.46 times higher dryer throughput compared to the fresh pineapple. Islam (1980) found that 3 to 5 times higher dryer throughput in drying osmosed potato, while Uddin and Islam (1985) reported 7.5 times higher throughput by drying osmosed pineapple than fresh ones.

3.4 Kinetics of vitamin C

3.4.1 Mechanical drying on vitamin C content

To observe the effect of drying time on vitamin C content of pineapple at three different temperatures were dried for periods up to 4 h at 55 °C, 60 °C and 65 °C temperature. Vitamin C concentration ratio (C_t/C_0) versus time (h) was plotted on a semi-log coordinate, (not shown in figure) and the following regression equations were developed:

$$C_t/C_0 = 0.989e^{-0.06t} \qquad (55 °C) \qquad (23)$$
$$C_t/C_0 = 0.973e^{-0.09t} \qquad (60 °C) \qquad (24)$$
$$C_t/C_0 = 0.965e^{-0.11t} \qquad (65 °C) \qquad (25)$$

where, C_0 = initial vitamin C concentration (mg 100g^{-1}), C_t = vitamin C concentration at time, t, and t = time in h.
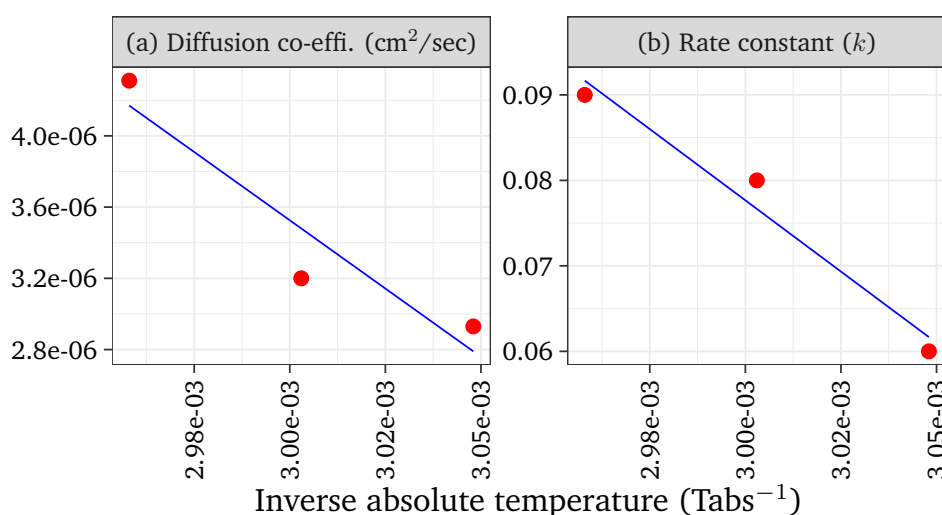
Figure 7. Effect of temperature on (a) diffusion co-efficient, and (b) rate constant k (h^{-1}) of 6 mm thick fresh pineapple slices

From equations Equation 23–25, it is found that as exposure time increases at constant drying temperature, vitamin C content of pineapple decreases and the ratio of vitamin C concentration (C_t/C_0) decreases exponentially with time. It is also observed that for a given exposure time the concentration ratio decreases with increase in temperature or in other words rate constant increases as temperature is increased.

It is obvious that during drying, % loss of vitamin C is accelerated by air and heat. Damodaran et al. (2010) reported that the vitamin C degradation is dependent on temperature. Hendel et al. (1955) observed that about half of the ascorbic acid is usually lost during drying, but wide variations are to be expected. For process optimization and to compare the effect of drying temperature on reaction rate constant of vitamin C content of pineapple, reaction rate constant values versus inverse absolute temperature (Tabs^{-1}) were plotted on a semi-log co-ordinate and regression lines were drawn (Fig. 7b) as per Arrhenius equation. Accordingly, the following regression equation was developed:

$$y = 648.8e^{-7238t} \qquad (26)$$

According to Arrhenius equation rate constant (k) has an exponential relationship with inverse absolute temperature (1 Tabs^{-1}), the activation energy for degradation of vitamin C for pineapple is found to be 14.38 Kcal g-mole^{-1}. The kinetics of ascorbic acid degradation in pineapple has been studied by Gwala and R (2015) who observed that ascorbic acid degradation followed 1st order reaction kinetics where the rate constant increased with an increase in temperature. The Activation energy was found to be 17.82 kJ mole^{-1} for pineapple juice by Hong et al. (2002).

3.4.2 Effect of osmosis on vitamin C content

To observe the effect of osmosis on vitamin C content of pineapple during drying, 6 mm thick pineapple slices of 55/5% sugar/salt solution was osmosed for 6 h and dried for periods up to 4 h at 60 °C temperature. Vitamin C concentration ratio (C_t/C_0) versus time (hour) was plotted on a semi-log coordinate (Fig. 6b) and regression lines were drawn:

$$C_t/C_0 = 0.973e^{-0.06t} \qquad \text{(osmosed)} \qquad (27)$$

$$C_t/C_0 = 0.999e^{-0.09t} \qquad \text{(fresh)} \qquad (28)$$

From Fig. 6b and Equation 27-28, it is seen that as exposure time increase at constant drying temperature, ratio of vitamin C concentration (C_t/C_0) decreases exponentially with time. It also observed that the k value of degradation of vitamin C of osmosed sample was 0.06 h^{-1} and that for fresh sample was 0.09 h^{-1} at 60 °C drying temperature, which indicates that osmotic dehydration has positive effect on the retention of ascorbic acid during air-drying. Heng et al. (1990) observed similar behavior during studies on osmotic dehydration of papaya.

3.5 Composition of dried pineapple and developed jam

Jam was prepared using fresh, mechanically dried and osmo-dehydrated (55/5% sugar/salt) pineapple. Dehydrated pineapple slices and jams analyzed for different parameters like moisture content, acidity, PH and vitamin C. Table 4 and Table 5 show the composition of dried pineapple and jam. Table 4 gives the similar to that described by Riva et al. (2005) who studied the osmo-air dehydration process in order to improve the quality of dried apricots.

3.6 Sensory evaluation of pineapple jam

Jam samples were prepared from fresh pineapple, 55/5% sugar/salt osmosed pineapple and mechanically dried pineapple subjected to organoleptic taste testing using 1-9 hedonic scale. The mean scores for color, flavor, texture and overall acceptability of pineapple jams are present in Table 6.

A two-way analysis of variance (ANOVA) was carried out for color, flavor, texture and overall acceptability and results revealed (Table 6) that there was significant ($p < 0.05$) difference in color, flavor, texture and overall acceptability among the samples. Thus it is seen that in all respect, jam made from osmosed (55/5% sugar/salt) was the best product and is ranked as 'like very much'. The other products are also acceptable and ranked as 'like moderately'.

Table 4. Composition of dried pineapple

Composition (%)	Mechanical		Osmosed	
	wb	db	wb	db
Moisture	14.7	17.19	9.84	10.92
Acidity	1.04	1.15	1.39	1.62
Vitamin C (mg 100g^{-1})	7.5	8.78	9.14	10.14

Mechanical = mechanical drying, osmosed = 55/5% sugar/salt osmosed and dried mechanically, wb and db designate weight and dry basis, respectively.

Table 5. Composition of pineapple jams

Composition (%)	Sample Code		
	505	606	707
Moisture	35.5	30.75	33.59
Acidity	0.384	0.512	0.496
Vitamin C (mg 100g^{-1})	8.6	8.12	5.12
pH	3.9	3.6	3.82

Here, 505 =jam made from fresh pineapple pulp, 606 = jam made from pineapple pulp osmosed by 55/5% sugar/salt solution then dried and 707= jam made from mechanically dried pineapple pulp. Values are in dry basis.

Table 6. Mean score for color, flavor, texture and overall acceptability of jams

Sample	Color	Flavor	Texture	Acceptability
505	7.8b	8.1b	7.6a	7.8b
606	8.7a	8.7a	8.0a	8.5a
707	7.0c	7.6c	6.7b	7.0c

Here, 505 =jam made from fresh pineapple pulp, 606 = jam made from pineapple pulp osmosed by 55/5% sugar/salt solution then dried and 707= jam made from mechanically dried pineapple pulp.

4 Conclusions

The study showed that there is a good prospect of processing of pineapple by osmotic dehydration and/or air drying as value added product. By processing pineapple its production can be maximized. Further research in optimizing process variables for high quality products should be carried out to produce for export market.

Acknowledgements

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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