Mass exchange during osmotic drying of ginger treated banana slices

Deep P Patel, Dr. SK Jain, Dr. NK Jain and Dr. SS Lakhawat

Abstract
The ripe banana slices of 20 mm thickness were osmo dried by immersing them in sugar syrup solutions of three different concentrations 40, 50 and 60 °Brix mixed with ginger juice (12:1) at three different osmotic temperatures 35, 45 and 55 °C having the solution to sample ratio 5:1 for five hours. The effect of process parameters during osmotic dehydration such as duration of osmosis, concentrations and temperatures of sugar solution on water loss, sugar gain and weight reduction were evaluated. It was found that the water loss, sugar gain and weight reduction increased with an increase of syrup concentration and temperature. The initial moisture content of banana samples was 75.5-78.5% (wb), which was reduced to 61.1-68.02% (wb). After 5 hours of osmotic dehydration, the minimum and maximum water loss, sugar gain and weight reduction were found in the range of 9.41 to 28.63, 3.86 to 6.79 and 5.55 to 24.34 per cent, corresponding to low levels (40 °Brix, 35 °C) and high levels (60 °Brix, 55 °C) of syrup concentration and temperature, respectively. The regression equations of second order polynomial were found to predict the kinetics of osmotic dehydration process of banana slices.

Keywords: Banana, osmotic drying, water loss, sugar gain, weight reduction

1. Introduction
Banana (Musa spp.) is a perennial plant, which is grown in almost all countries and considered as the fourth most harvested agriculture product after rice, wheat, and maize (Hailu et al., 2013) [7]. It is an important fruit crop of many tropical and subtropical regions of India. It is cultivated in an area of 830.5 thousand ha and total production is around 29,779.91 thousand tons in India. Tamil Nadu, Maharashtra, Gujarat, Andhra Pradesh and Karnataka are the main banana growing states (FAO, 2017) [4].

Banana has a high nutrition value and is a good source of energy due to its high level of starch and sugar, as well as being a source of vitamins A and C, potassium, calcium, sodium and magnesium. It is easy to digest, free from fat and cholesterol. It helps in reducing the risk of heart diseases when used regularly and is recommended for patients suffering from high blood pressure, arthritis, ulcer, gastroenteritis and kidney disorders (Sousa et al., 2003) [23].

The various commercial products made from bananas are like pulp, puree, jam, jelly, juice, toffee, wine, halwa, fig, flour, flakes, canning of banana, deep fat fried chips, powder, fruits bar, squash, brandy, etc. before it perishes (subagyo et al., 2018) [25].

Fruits and vegetable losses in developing countries are considerably going high. In India, post-harvest losses of fruits and vegetables are estimated at more than 25 percent. Many processing techniques can be employed to preserve fruits and vegetables among them drying and dehydration are one of the most important techniques that are widely practiced because of considerable saving in packaging, storage, etc (Chavan, 2012) [3].

Generally, during dehydration, fruits are subjected to conventional tray dryer or vacuum dryer, which do not keep the original flavor, texture, color and some nutrients (Jain and Verma, 2011) [8]. While, freeze drying of fruit gives high quality food products but at the same time it attributes the high cost of processing (Gharsallaoui et al., 2007) [6].

Osmotic dehydration is one of the most significant complementary treatment and food preservation practice in the processing of dehydrated foods since it offers some benefits such as reducing the damage of heat to the color, flavor, inhibiting the browning of enzymes and decrease the energy costs (Torres et al., 2012) [27]. It is utilized for partial removal of water from the food materials like fruits and vegetable by immersing them in aqueous solutions of high osmotic pressure such as salt and sugar (Pandharipande et al., 2012) [17]. Some factors have been employed to speed up water removal such as using a high concentration of the
osmotic solution, the low molecular weight of osmotic agent, high osmotic temperature, stirring process or some pre-treatment techniques (Garcia et al., 2010) [3].

Many researcher studied osmotic dehydration characteristics of different fruits and vegetables, such as banana carrot, cherry, apple, sapota, kiwifruit, mushroom, papaya, guava, mango, etc. (Sethi et al., 1999; Torreggiani and Bertolo, 2001; Jain et al., 2011; Mehta et al., 2018; Kaur et al., 2018) [24, 26, 8, 14, 11].

2. Materials and Methods

2.1 Raw materials preparation

Firm banana of good variety viz. Grand Naine was used in the investigation which is suitable for products like chips, powder, etc. It is high yielding, long cylindrical with less curvature and attractive color variety. The fruits were procured from the local vegetable market of Udaipur (India).

After peeling, slicing of ripe banana was done with the help of a stainless steel knife to get 20 mm thick slices. Sugar solution of desired (40, 50 and 60 °Brix) concentration was prepared by dissolving the required amount of sugar in water. The total soluble solids of prepared solutions was found out by using hand refractometer of two different ranges (0-53, 53-92 °Brix), which gave the reading directly in Brix (Ranganna, 2002) [21]. The moisture content of the fresh, as well as osmotically dehydrated banana samples, was determined by using Ranganna (2002) [21] method.

2.2 Experimental set up and procedure for osmotic drying

2.2.1 Experimental set up

A small size capacity laboratory temperature controller water bath was used as osmotic dehydration unit which consists of a water bath of size 45 cm x 40 cm x 30cm (approximate capacity, 7 litres) and temperature controller probe was used to regulate the required water temperature in the investigation.

2.2.2 Experimental procedure for osmosis

Experiments were conducted at nine combinations of three concentrations (40, 50 and 60 °Brix) and three temperatures (35, 45 and 45 °C). The banana slices of 20 mm thickness, the sample to solution ratio of 1:5 were kept constant for all the combinations. In osmotic drying, samples (banana slices) were weighed approximately 50g for each experiment and immersed in 230 ml sugar solutions (40, 50 and 60 °Brix) mixed with 20 ml ginger juice in a 500 ml glass beakers. The beakers were placed inside the constant temperature controlled water bath. The syrup in the beakers was manually stirred at fix intervals to maintain the constant temperature. One beaker was taken out from the water bath at the designated time (after each 30 min interval), samples were removed and placed on absorbent paper for 5 min or were immediately rinsed in flowing water and placed on tissue paper to remove the surface moisture to eliminate excess syrup from the surface before weighing. And finally, the samples were weighed and their moisture contents were determined. The water loss, sugar gain and weight reduction were calculated on a wet basis by equations (1, 2 and 3 respectively) as described below.

2.3 Mass Transport in Osmosis

Lenart and Flink (1984) [13] first defined terminologies for mass transport data which helped to study the behavior of the osmosis process during dehydration of different products and the same has been used by various researchers such as Kaleemullah et al., 2002 [9]; Jain et al. 2011 [8]; Pisalkar et al., 2011 [18] and Kaur et al., 2018 [11]. The terminologies are as follows:

2.3.1 Water loss

Water loss is the amount of water lost by food during osmotic processing. It is defined as the net weight loss of the fruit on an initial weight basis and is estimated as

\[ WL = \frac{W_i X_i - W_\theta X_\theta}{W_i} \times 100 \]  \hspace{1cm} (1)

Where,

- \( WL \) = water loss (g per 100 g mass of the sample).
- \( W_\theta \) = mass of slices after time \( \theta \), g
- \( W_i \) = initial mass of slices, g
- \( X_\theta \) = water content as a fraction of mass of slices at time \( \theta \), fraction
- \( X_i \) = water content as a fraction of initial mass of slices, fraction

2.3.2 Sugar gain

The sugar from the osmotic solution gets added to the sample of unripe banana slices during osmotic dehydration. The loss of water from the sample takes place in osmotic dehydration consequently it increases the sugar content. The sugar gain is the net uptake of sugar by the slices on an initial weight basis. It was computed using the following expression:

\[ SG = \frac{W_\theta (1 - X_\theta) - W_i (1 - X_i)}{W_i} \times 100 \]  \hspace{1cm} (2)

Where,

- \( SG \) = sugar gain (g per 100 g mass of sample).

2.3.3 Weight reduction

The weight reduction (WR) can be defined as the net weight loss of the fruit material on an initial weight basis.

\[ WR = \frac{W_i - W_\theta}{W_i} \times 100 \]  \hspace{1cm} (3)

Where

- \( WR \) = weight reduction

3. Results and Discussion

3.1 Initial moisture content

The initial moisture content of banana slices was determined by oven drying method. The average initial moisture content of banana was found as 76.2 percent (wb).

3.2 Water loss in osmosis

The water loss increased from 0 to 9.41, 12.18 and 24.60 per cent when the duration of osmosis increased from 0 to 5 hrs for 40 °Brix syrup concentration at 35, 45 and 55 °C temperatures respectively. For 50 °Brix concentration, the water loss was found to be in the range of 0 to 10.31, 14.96, and 24.67 per cent. Also for 60 °Brix, it was found to increase from 0 to 14.72, 17.43 and 28.63 per cent at 35, 45 and 55 °C osmosis temperatures respectively.

Figure 1 revealed that a low temperature low concentration condition (35°C - 40 °Brix) resulted in a low water loss (9.41 percent after 5 h of osmosis) and a high temp high
concentration condition (55 °C - 60 °Brix) resulted in a higher water loss (28.63 per cent after 5 h of osmosis). This signifies that water loss can be increased by either increasing syrup concentration or temperature. A similar result has been cited for osmotic dehydration of bananas by Sagar (2001). Such properties were also cited for various fruits and vegetables (Ertekin and Cakaloz, 1996; Karathanos et al., 1995; Lazarides et al., 1995; Pokharkar and Prasad, 1998).

Figure 2 indicates the variation in water loss in 40, 50 and 60 °Brix concentrations of the solution at temperatures 35, 45 and 55 °C. The water loss was found increasing at all the three solution temperatures i.e., at 35, 45 and 55 °C with increasing osmotic solution concentrations.

These effects were in confirmation with the results obtained. In all the treatments, the rate of water loss was more at the beginning of the osmosis process and decreased gradually with the increase in the duration of osmosis. The similar outcomes have been noted in the case of the osmotic dehydration of banana slices (Pokharkar and Prasad, 1997) and green beans (Biswal and Bozorgmehr, 1991). Increased water loss with the increase in the concentration of solution at a particular temperature of syrup may be caused by increased osmotic pressure in the syrup at higher concentrations of the solution, which increased the driving force available for water transport. This is given in agreement with Nieuwenhuijzen et al., 2001.
3.3 Sugar gain in osmosis

It can be observed from the data that when syrup temperature was increased from 35, 45 and 55 °C for 40 °Brix concentration, the sugar gain increased from 0 to 3.86, 4.87 and 5.32 per cent respectively, when the duration of osmotic drying increased from 0 to 5 hrs. In addition to for 50 °Brix concentration, the sugar gain was increased from 0 to 4.23, 5.11 and 5.83. However for further increase in syrup concentration to 60 °Brix, the sugar gain was 0 to 5.61, 6.36 and 6.79 per cent for 35, 45 and 55 °C syrup temperatures in the same period of osmosis.

Figure 3 shows that sugar gain increased with duration of osmosis but doesn’t approach to equilibrium after 5 hrs of osmotic drying. The sugar gain also increased when the concentrations of the solution were increased. This is due to the increased concentration difference between samples. It also increased with increase in syrup temperature. It may be because of the collapse of the cell membrane at higher temperatures. Similar results were quoted by Ertekin and Cakaloz, (1996) [3] and Nsonzi and Ramaswamy, (1998) [16].

![Figure 3: Variation in sugar gain with the duration of osmosis for various syrup concentrations 35, 45 and 55°C syrup temperatures](image)

Figure 4 shows the variations in sugar gain at various temperatures for 40, 50 and 60 ° Brix concentrations. A low temperature-low concentration condition (35 °C-40 °Brix) gives a low sugar gain (3.86 per cent after 5 hrs of osmosis) and a high temperature-high concentration condition (55 °C-60 °Brix) gives a higher sugar gain (6.79 per cent after 5 hrs of osmosis). The low temperature-high concentration condition 35 °C-50 °Brix and 35 °C-60 °Brix gives a slightly lower sugar gain of 4.23 and 5.61 after 5 hrs of osmosis than high temperature-high syrup concentration condition 55 °C-50 °Brix and 55 °C-60 °Brix as 5.83 and 6.79 per cent sugar gain after 5 hrs of osmosis indicates a pronounced effect of temperature on sugar gain.

![Figure 4: Variation in sugar gain with the duration of osmosis for various syrup temperatures and syrup concentrations of 40, 50 and 60°Brix](image)
This means that sugar gain can be increased by either increasing the syrup temperature or concentration of the solution. However, an increase in temperature of sugar solution by 10 °C has more influence on sugar gain than an increase in concentration by 10 °Brix, maybe because of higher temperature causes the destruction of cell membrane structure. This is given in agreement of Lazarides et al. (1999) \(^\text{[12]}\) for osmotic dehydration of apple slices in a temperature range from 20-50 °C.

3.4 Weight reduction in osmosis

The minimum and maximum weight reduction after osmotic drying was found to be in the range of 5.55 to 24.34 per cent, respectively, corresponding to experiments at low level (40 °Brix, 35 °C after 5 h) and at high level (60 °Brix, 55 °C after 5 hrs) shown in figure 5.

Figure 5 shows that a low temperature low concentration condition (35 °C-40 °Brix) resulted in a low weight reduction (5.55 per cent after 5 hrs of osmosis) and a high temp-high concentration condition (55 °C-60 °Brix) resulted in a higher weight reduction (30.25 per cent after 5 hrs of osmosis). This indicates that weight reduction can be increased by either increasing the syrup temperature or concentration of solution. Similar result was quoted for osmotic dehydration of onions by Torreggiani and Bertolo (2001) \(^\text{[26]}\).

**Figure 5:** Variation in weight reduction with the duration of osmosis for various syrup concentrations 35, 45 and 55°C syrup temperatures

The weight reduction raised from 0 to 5.55, 7.37 and 15.85 percent when duration of osmotic drying increased from 0 to 5 hrs at 35, 45 and 55 °C temperatures respectively for 40 °Brix. Similarly for 50 and 60 °Brix, the weight reduction was found to vary from 0 to 6.67, 12.48 and 22.25 per cent and 0 to 8.39, 13.75 and 24.34 per cent at 35, 45 and 55 °C temperatures respectively.

**Figure 6:** Variation in weight reduction with the duration of osmosis for various syrup temperatures and syrup concentrations of 40, 50 and 60 Brix

Figure 6 shows the variation in weight reduction at 40, 50 and 60 °Brix concentration of the solution at 35, 45 and 55 °C temperatures. The weight reduction at all syrup concentrations was affected by the temperature of the syrup. Hence, weight reduction increased with increase in temperatures.

**The statistical analysis**

The statistical analysis revealed that second order polynomial equation provided best fit to the observed values of mass reduction, water loss and sugar gain. The predicted equations with their coefficient of determination values are presented in the Table.1.
In general the polynomial equation of second order in the following form was predicted.

\[ Y = aX^2 + bX + c \]

Where, 
\( Y = \) Mass reduction, water loss and sugar gain in percent,
\( a, b, c = \) Constants and
\( X = \) Duration of osmosis in min.

It was observed that the values of the coefficient of determination were more than 0.90 for all the experiment condition which revealed the good determination between the predicted and observed data.

4. Conclusion

Duration of osmosis, Syrup concentration and temperature of the solution had a definite effect on the kinetics of osmotic drying of banana samples. In osmotic drying of banana slices, an increase of duration, temperature and concentration of sugar solution increases water loss, weight reduction and sugar gain. After five hours of osmotic drying, the minimum and maximum water loss, sugar gain and weight reduction were in the range of 9.41 to 28.63, 3.86 to 6.79 and 5.55 to 24.34 per cent corresponding to low levels (40 °Brix, 35 °C) and high levels (60 °Brix, 55 °C) of syrup concentration and temperature, respectively. The temperature of syrup was found to be the most influencing factor followed by concentration of syrup and duration of osmosis was least effective for all the responses viz. weight reduction, water loss and sugar gain. Osmosis as a pre-treatment prior to any drying can be used to reduce drying time. The regression equations of second order polynomial were found to predict the kinetics of osmotic dehydration process of banana slices.

5. References


Table 1: Predicted equations and coefficient of determination values for water loss, sugar gain and weight reduction

<table>
<thead>
<tr>
<th>Variables</th>
<th>Syrup concentration (ºBrix)</th>
<th>Temperature of osmotic solution (°C)</th>
<th>Equation predicted</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight reduction</td>
<td>40</td>
<td>35</td>
<td>( y = -0.0001x^2 + 0.1401x + 1.1395 )</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>( y = -0.0001x^2 + 0.1599x + 2.3351 )</td>
<td>0.98</td>
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<td></td>
<td>55</td>
<td>( y = -0.0001x^2 + 0.1632x + 2.4231 )</td>
<td>0.98</td>
<td></td>
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<tr>
<td></td>
<td>50</td>
<td>35</td>
<td>( y = -0.0001x^2 + 0.1541x + 1.7607 )</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>45</td>
<td>( y = -0.0002x^2 + 0.1780x + 4.048 )</td>
<td>0.94</td>
<td></td>
</tr>
<tr>
<td></td>
<td>55</td>
<td>( y = -0.0002x^2 + 0.1908x + 4.721 )</td>
<td>0.93</td>
<td></td>
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<tr>
<td></td>
<td>60</td>
<td>3</td>
<td>( y = -0.0002x^2 + 0.1629x + 2.916 )</td>
<td>0.97</td>
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<td></td>
<td></td>
<td>45</td>
<td>( y = -0.0003x^2 + 0.2009x + 4.356 )</td>
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</tr>
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<td></td>
<td></td>
<td>55</td>
<td>( y = -0.0003x^2 + 0.2149x + 4.741 )</td>
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</tr>
<tr>
<td>Water loss</td>
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<td>35</td>
<td>( y = -0.0003x^2 + 0.1658x + 1.4839 )</td>
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<td>( y = -0.0003x^2 + 0.1816x + 2.9575 )</td>
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<td></td>
<td></td>
<td>55</td>
<td>( y = -0.0004x^2 + 0.2004x + 3.232 )</td>
<td>0.97</td>
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<td></td>
<td>60</td>
<td>( y = -0.0004x^2 + 0.1798x + 2.828 )</td>
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<td>( y = -0.0004x^2 + 0.2067x + 4.7105 )</td>
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<td>( y = -0.0004x^2 + 0.2288x + 4.986 )</td>
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<tr>
<td></td>
<td></td>
<td>60</td>
<td>( y = -0.0005x^2 + 0.1818x + 3.5374 )</td>
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<td>( y = -0.0005x^2 + 0.2281x + 5.303 )</td>
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<td>55</td>
<td>( y = -0.0005x^2 + 0.2468x + 6.696 )</td>
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<tr>
<td>Sugar gain</td>
<td>50</td>
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<td>( y = -0.0005x^2 + 0.0257x + 3.443 )</td>
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<td>( y = -0.0007x^2 + 0.0252x + 6.213 )</td>
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<td></td>
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<td>60</td>
<td>( y = -0.0007x^2 + 0.0420x + 6.914 )</td>
<td>0.91</td>
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</table>


