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Drying and Dehydration Kinetics of Ginger

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ABSTRACT: The experiment was conducted to study the drying behavior of ginger using mechanical drier and osmotic dehydration and development of dehydrated ginger products. Three different thicknesses (3, 5 and 7mm slice) and three different temperatures (52^{o}C, 60^{o}C and 68^{o}C) were used in this study for ginger drying. The study revealed that 3mm thick slice required the least time to dry, followed by 5mm thick slice, while the highest drying time was for 7mm thick slice. It was also noticeable that for reaching to a specific moisture ratio, 68^{o}C temperature took least time to dry, followed by 60^{o}C, while highest was required at 52^{o}C. The influence of air temperature (db) on drying rate constant and diffusion coefficient showed Arrhenius type relationship between diffusion coefficient and absolute temperature. The activation energy for diffusion of water from ginger was found 15.868 Kcal/g-mole. The influence of sample thickness on drying time showed a power law relationship. The value of exponent of power law equation is 0.5315 which indicated the presence of significant amount of external mass transfer resistance. The rate of extent of weight loss , moisture content, solid gained and normalised solid content (NSC) were strongly influenced by strength of osmotic solution, immersion time and were rapid during the first 6 hrs of osmotic dehydration.

KEYWORDS: ginger, drying, osmotic dehydration, drying rate constant, diffusion coefficient, activation energy.

1 INTRODUCTION

Ginger (*Zingiber officinale Roscoe*) is important cash and one of the principal spice crops all over the Bangladesh and world. India is the largest producer, consumer and exporter in the world. Ginger of commerce is the dried rhizome prepared from the fresh rhizomes. It plays a significant role in earning valuable foreign exchange. It is marketed in different forms such as raw ginger, dry ginger, bleached dry ginger, ginger powder, ginger oil, ginger oleoresin, gingerale, ginger candy, ginger beer, brined ginger, ginger wine, ginger squash, ginger flakes, etc. Chinese ginger is usually not exported as a dried spice, but preserved in sugar syrup or converted into 'ginger candy'.

Ginger is seasonal in nature and available in large quantities during the peak season in the local market. But due to higher water activity (a_w), ginger cannot be kept for longer time after harvesting. Ginger is normally stored in pit but within few days sprout and roots are found. In this situation the farmers do not sell them without removing sprout and rooting part from ginger. That's why additional labour cost is required. Sometime decay or rotting is found due to higher moisture in pit. But if ginger is kept out of pit it become shrivel within few days. In this case the farmers do not get good price. If spoilage/postharvest losses could be reduced to an acceptable level by proper processing/preservation; farmers would get proper price of their products and thus be encouraged to increase yield and production

Proper drying techniques as well as proper slice thickness of product are required for obtaining good quality dried products. Drying of ginger are carried out by open sun drying, solar or mechanical drying. Thus, it is important to know the drying characteristics of this crop. The drying rate of ginger is closely associated with the drying air temperatures, relative humidity and air velocity. One of the most important criteria of food is colour. Undesirable changes in the colour of food may lead to a decrease in consumer's acceptance as well as market value. Hence, it is necessary to dry ginger in a suitable environment to produce good quality stable dried products. The efficiency of drying system can be improved by the analysis of the drying process.

Hot air dehydration has been largely employed to preserve fruits and vegetables. In this case, simultaneous mass and heat transfer takes place. In order to obtain high quality dehydrated food, osmotic dehydration has been introduced as a pretreatment by immersion in liquids with lower water activity than that of the food. Through pretreatment before air drying moisture is reduced from 30% to 70% of the water content of the food [14]. Also, energy consumption is reduced [13]. However, osmotic dehydration will usually not lead to sufficiently low moisture content for the product to be considered shelf-stable [16]. The osmotic dehydration process carries out at the same time of removing of water and direct preparation of product [14].

Osmotic dehydration preceding air drying decreases colour changes and increases flavour retention in dried fruits and vegetables [6]. The resulting product has generally better quality than the dried one without pretreatment.

2 MATERIALS AND METHODS

The present study was undertaken to determine drying kinetics of ginger using mechanical and osmotic dehydration and to optimize process parameter to obtained high quality dried products. Fresh ginger (BARI Ada-1) was collected from the Bangladesh Agricultural Research Institute (BARI), Spices Research Center (SRC) farm. The other materials such as sugar, salt, chemicals etc purchased from market.

2.1 LABORATORY DRYER

The experiments of a single layer drying of ginger at different thickness and various air temperatures were conducted in laboratory type mechanical dryer (Fisher, Model 438 F). The dryer mainly consisted of a blower, heating unit, drying chamber and sample container. It was adjusted with the thermostat to control the temperature in the drying chamber.

2.2 SELECTION OF SLICE THICKNESS AND DRYING TEMPERATURE

Ginger was sliced to three different thicknesses (3, 5 and 7mm) by sterilized slicer. Three different slice thicknesses (3, 5 and 7mm) of ginger were selected for this study. Usually spices are being dried within the temperature range of 60 to 85^{o}C. At lower drying temperature products were dried for longer time and it caused a change in browning colour in the final dried products which is undesirable for consumer acceptance. Case hardening occurred at higher drying temperature generally above 70^{0}C drying in most of the spices. Outer surface was over dried hence caused disintegration of moisture diffusion from the interior part of the product during drying. The final dried material could not be regarded as good quality due to no-uniform drying. Therefore, 52, 60 and 68^{o}C temperature were selected for safe drying of ginger.

2.3 MECHANICAL DRYING

Sliced samples were placed on the tray in a thin layer in a mechanical drier. Samples were dried until the products were reached in equilibrium moisture content. Air flow and RH were maintained constant in the drier. Dehydrated ginger product was grinded in a grinding machine. This powder were packed in HDPE, Al-foil and stored at room and refrigeration temperature for shelf life study.

2.4 THEORETICAL DRYING EQUATIONS

Ficks second law is applied to describe mass transfer during drying since food dehydration is assumed to be a diffusion process. The expression is:

$$\frac{\delta M}{\delta t} = \Delta^2 D_e M \qquad \text{(i)}$$

Where,

M= Moisture content (dry basis), T= Time and D_e= Effective diffusion co-efficient.

To find a solution of the above unsteady state diffusion equation for one dimensional transport for the case of initial uniform moisture distribution in the sample and negligible external resistance, appropriate boundary conditions are assumed. The solution for an infinite slab (with thickness, L), when dried from one major face ([3], [10], [4])

$$MR = \frac{Mt - Me}{Mo - Me} = \frac{8}{\pi^2} \sum_{n=0}^{\alpha} \frac{1}{(2n+1)^2} Exp \frac{-(2n+1)^2 \pi^2 D_e t}{L^2} \qquad \text{(ii)}$$

Where, MR= Moisture ratio, M_t, M_o and M_e are the moisture content at the time t, initial moisture content and equilibrium moisture content respectively. MR can be calculated from equation ii. When MR versus drying time (hr) was plotted on a semi-log graph, drying rate graphs can be drawn. Consequently, a straight line should be obtained when plotting In MR versus time (t). The slope of the regression line is the drying rate constant, m from which the effective diffusion co-efficient, D_e is calculated.

2.5 SEMI THEORETICAL DRYING EQUATIONS

For low M_e values and for moisture ratio, MR<0.6 equation (i) reduces to:

$$\frac{M_t}{M_0} = \frac{8}{\pi^2} e^{-\pi^2 D_e t / L^2} = \frac{8}{\pi^2} e^{-mt} \qquad \text{(iii)}$$

Where, m = $\frac{\pi^2 D_e}{L^2}$ = drying rate constant, sec^{-1}

Re-arranging equation (ii) gives:

$$In(\frac{M_t}{M_0}) = In(\frac{8}{\pi^2}) - mt \qquad \text{(iv)}$$

From the semi-theoretical equation as shown in equation (iii), it may be noted that the drying rate constant, m is a function of the square of thickness of the product dehydrated, as

$$m = \frac{\pi^2 D_e}{L^2} \qquad \text{(v)}$$

2.6 DIFFUSION COEFFICIENT AND ACTIVATION ENERGY

The effective moisture diffusivity can be expressed by simple Arrhenius equation as a function of temperature as follows

The relationship is as follows [8].

$$\frac{dInD_e}{dT_{abs}} = \frac{E_a}{RT_{abs}}$$

or, In D_e = In D_o - $\frac{E_a}{RT_{abs}}$ (vi)

Where, D_o is constant equivalent to the diffusivity at infinitively high temperature (m^2/s), E_a is the activation energy of diffusion of water (cal/g-mole), R is the universal gas constant (8.314×10^{-3} kJ/mol K) and T_{abs} is the absolute temperature, ^oK.

From equation (vi), it is apparent that plotting diffusion co-efficient (D_e) versus the inverse absolute temperature on semi-logarithmic co-ordinates would lead to the evaluation of activation energy for diffusion of moisture during drying and activation energy was calculated by non-linear regression analysis.

2.7 OSMOTIC DEHYDRATION

Ginger were washed and sliced into 3, 5 and 7 mm thickness and initial moisture content was determined by oven drying method. Each slice were weighed and subsequently individually marked by using different coloured threads. Pieces were immersed into 40%, 50%, 60% sucrose and 45/15%, 50/10% and 55/5% sucrose-salt solutions at room temperature (25^{o}C) for different period of times, such as ½ hr, 1 hr, 2 hr, 4 hr , 6 hr. After the end of each definite time interval the slices were removed and quickly rinsed in water. Subsequently, surface water was removed by gently blotting with tissue-paper. The ratio of sugar to ginger slices was 5:1 w/w.

After weighing the slices at definite time interval, moisture content of each individual sample 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 solids (%TS) and Normalized solid content (NSC) were determined according to the standard formula reported by Hawkes and Flink (1978) [7].

The osmosed and nonosmosed ginger slices were placed in trays in single layer and drying was started in the cabinet dryer at 60^{o}C. Weight loss was gravimetrically determined to measure the extent of drying.

3 RESULTS AND DISCUSSION

In a mechanical dryer, 5 mm thick ginger slices were dried at three different air dry bulb temperatures at constant air flow and relative humidity to find the effect of temperature on drying time and another experiment was conducted to find the effects of thickness (such as 3, 5 and 7 mm thick) of ginger slices on drying time, when temperature and other conditions were kept constant.

3.1 EFFECT OF TEMPERATURE ON DRYING TIME OF GINGER SLICES

To determine the influence of temperature of drying time, 5 mm thick ginger slices were dried in a mechanical drier using three different air-dry bulb temperatures (52^{0}C, 60^{0}C and 68^{0}C). The experimental data were analyzed using equation (iv) and plots of moisture ratio versus drying time were made on semi-log co-ordinate and the regression lines were drawn. Accordingly, the following equations were developed:

$$MR = 0.9943e^{-0.1467t} \text{ (for } 52^0\text{C; t=hr)} \quad (1)$$

$$MR = 1.0538e^{-0.3357t} \text{ (for } 60^0\text{C; t=hr)} \quad (2)$$

$$MR = 1.0155e^{-0.4493t} \text{ (for } 68^0\text{C; t=hr)} \quad (3)$$

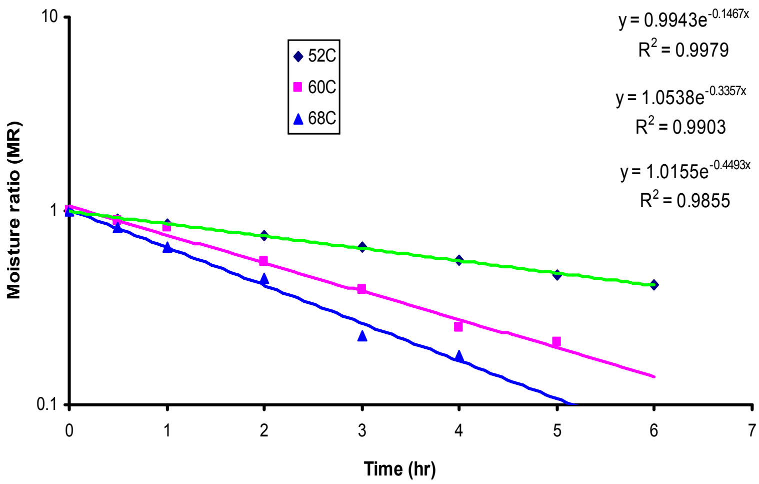

Fig.3.1 Effect of temperature on drying rate of ginger slices

From Fig (3.1) and the developed equation (1 to 3) it is clearly seen that when temperature is increased, drying rate constant is also increased. The drying time to a specific moisture ratio was decreased with the increase in drying temperature at constant sample thickness. As a result drying rate constant increased with increasing temperature. It was also noticeable that for a specific moisture ratio, the least drying time was achieved at 68° C, followed by 60°C, while the highest drying time was required at 52°C to dry 5 mm onion slice. The results are in agreement with Islam (1980) [10].

From the drying rate constant, the diffusion co-effcients were calculated. By plotting diffusion co-efficient (D_e) versus inverse absolute temperature ($1/T_{abs}$) in a semi-log scale (as per equation vi) a regression line was drawn (Fig 3.2). The equation of the straight line can be represented as (Fig. 3.2).

From the slope of the resultant straight line, activation energy (E_a) for diffusion of water for ginger was calculated and found to be 15.868 Kcal/g-mole.

Islam (198O) [10] found 7.7 Kcal/g-mole of activation energy for diffusion of water from potato and Uddin and Islam (1985) [19] found 8.4 Kcal/g-mole for pineapple. Babu *et al.* (1997) [2], however, found higher activation energy (26.83 Kcal/g-mole) for diffusion of water from onion. These differences in activation energy value from product to product are attributed due to product characteristics and process parameters as noted by Villota and Hawkes (1992) [21]. The dependence of diffusion coefficient on absolute temperature can be represented as:

$$D_e = 5E + 07\ e^{-7985.9}\ 1/T_{abs} \qquad (4)$$

Where, D_e=Diffusion coefficient (cm^2/s), T_{abs}= Absolute temperature

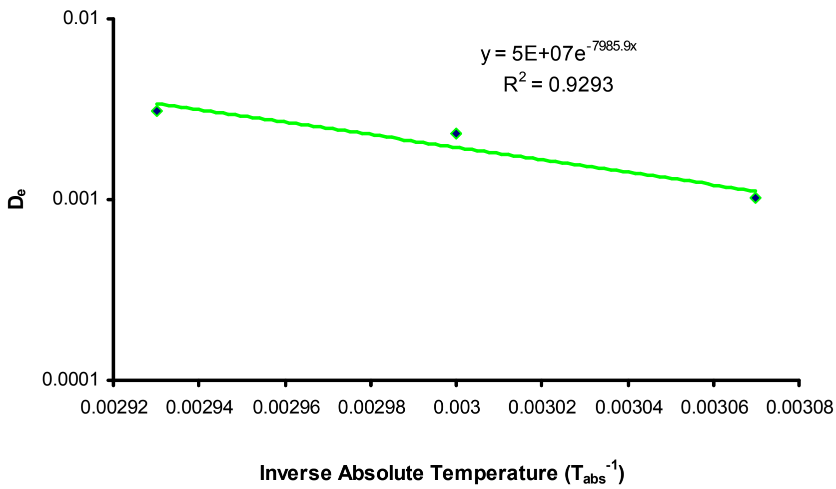

Fig.3.2 Effect of temperature on diffusion coefficient of ginger slices

3.2 EFFECT OF THICKNESS ON DRYING TIME

To investigate the influence of thickness on drying behavior 3, 5 and 7 mm slices were dried at a constant air dry bulb temperature (60^0C) and at constant air velocity in a cabinet dryer. The results were analyzed by using equation (iv) and moisture ratio (MR) versus drying time (hr) was plotted on a semi-log graph paper and regression lines were drawn (Fig 3.3). For the three different thicknesses of samples, the following regression equations were developed:

These are:

$MR=1.0124e^{-0.5512t}$ (for 3mm; t=hr) (5)

$MR=1.0538e^{-0.3357t}$ (for 5mm; t=hr) (6)

$MR=1.0425e^{-0.315t}$ (for 7mm; t=hr) (7)

The effect of different slice thicknesses on drying time is shown in Fig. 3.3 for ginger. The drying process took place in the falling rate period and no constant rate period was observed from the drying curves. From Fig 3.3 it was also observed that thickness had profound influence on drying time and as the thickness of the samples increased, the drying time to a specific moisture ratio also increased with resultant decrease in drying rate constant. It is also noticed that for a specific moisture ratio 3 mm thick slice required the least time, followed by 5 mm thick slice, while the highest time is required to dry 7mm thick ginger slice.

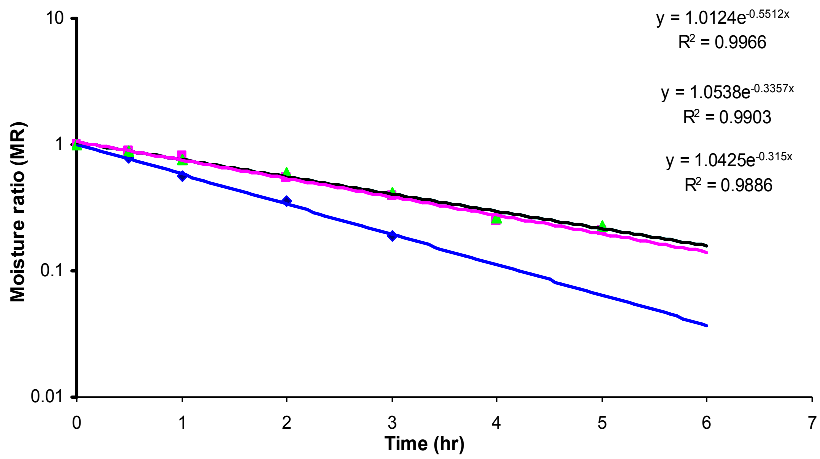

Fig.3.3 Effect of thickness on drying rate of ginger slices

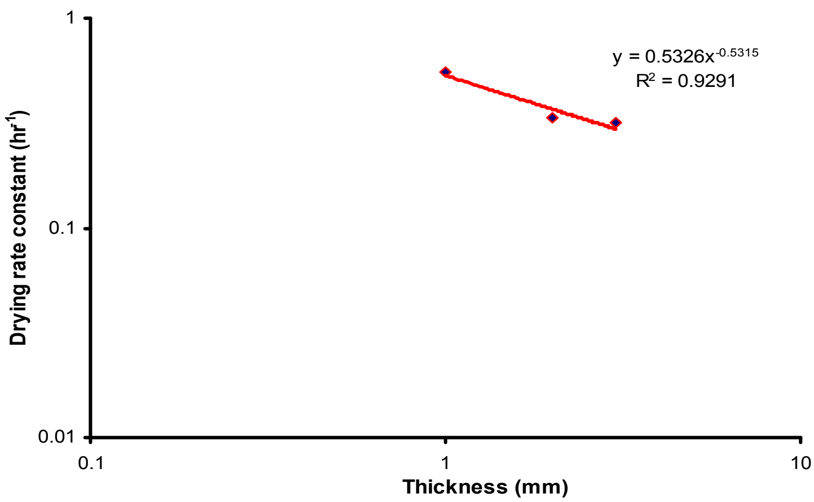

Fig.3.4 Effect of thickness on drying rate constant of ginger slices

The relationship between sample thickness and drying rate constant can be represented by power law equation as follows (Fig. 3.4).

$$m=0.5326L^{-0.5315} \qquad (8)$$

Where,

m= Drying rate constant (hr^{-1})

L= Sample thickness (mm)

From equation 8, it is seen that the value of the index ‘n’ for ginger is 0.5315. This value is quite lower than 2 as predicted by Fick’s unsteady state equation (iii) indicating that the external resistance to mass transfer was highly significant and internal resistance to mass transfer did not control the drying process under the given conditions. This conditions resulted primarily due to low airflow rate (<1 m/s), since similar samples did not indicate the presence of external mass transfer resistance under conditions of high air velocity (>2 m/s) as noted by Islam and Flink (1982 b). Islam (2003) found an n value of 1.57 for mechanical drying of indigenous varitey of onion and Hai (2002) found 0.49 for banana using similar air velocity (0.6m/s).

Table 1. Different drying parameter of mechanical drying system

Drying method	Sample thickness (mm)	Temperature (^{0}C)	Slope (hr)	Diffusion coefficient (D_e) cm^2/sec	Value of exponent (n value)	Activation energy (kcal/g-mole)
Mechanical	5	52	0.1467	1.02×10^{-6}		15.868
		60	0.3357	2.33×10^{-6}		
		68	0.4493	3.12×10^{-6}		
Mechanical	3	60	0.5512	1.38×10^{-6}	0.5315	
	5		0.3357	2.33×10^{-6}		
	7		0.315	4.29×10^{-6}		

3.3 OSMOTIC DEHYDRATION

The experiment is concerned with evaluation of osmotic concentration behavior of ginger measured by mass transfer parameters (influenced by type of solute (s), concentration of solute(s), immersion time). More specifically, the investigations include effect of solution concentration and time on percent water loss (WL), percent solid gain (SG) and normalized solid content (NSC) using different concentration of sucrose or salt alone or combined sucrose/salt solution on the basis of cost of solutes, their quality, availability at local market and organoleptic compatibility. Several authors ([9], [10], [15] [5]) indicated that 4 to 8 hrs osmotic time might be regarded as optimum time. It was, therefore, decided that minimum osmosis time would be 6 hours.

3.4 EFFECT OF SOLUTION (SUCROSE) CONCENTRATION AND TIME IN MOISTURE CONTENT OF GINGER SLICES

Effect of sucrose solution concentration (40, 50 and 60%) and sucrose-salt solution (45/15, 50/10 and 55/5%) on moisture content, percent water loss, solid gain and NSC at different time of 5 mm thick ginger slices is shown in Fig. 3.5 to 3.11. It was observed from Fig. 3.5 that 60% sucrose solution was the most effective among the solutions such as 40% and 50% sucrose solution when compared at the same immersion time interval. The result also showed that the higher the immersion time, the lower was the moisture content. As solution concentration increased osmotic pressure gradient also increased and thus resulted in more water loss as well as solute gain with resultant increase in solid concentration in the product. Higher solid concentration gave lower moisture content within osmosed sample as noted by Islam (1980) [10].

The result of another experiment for sucrose-salt solution (45/15, 50/10 and 55/5%) is shown in Fig. 3.6. It is seen from Fig. 3-6 that 55/5% sucrose/salt solution was the most accepted among the solutions tested when compared at the same immersion time interval. The result also showed that the higher the immersion time, the lower was the moisture content.

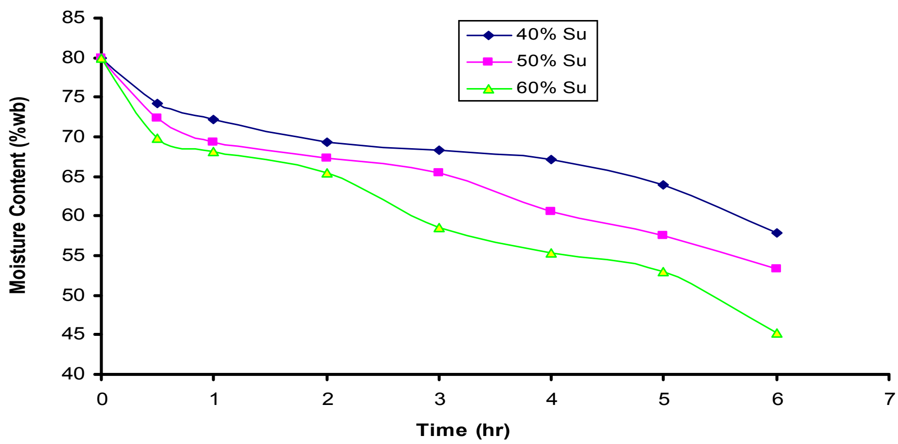

Fig.3.5 Change of moisture content of ginger slices with time in different sucrose solution

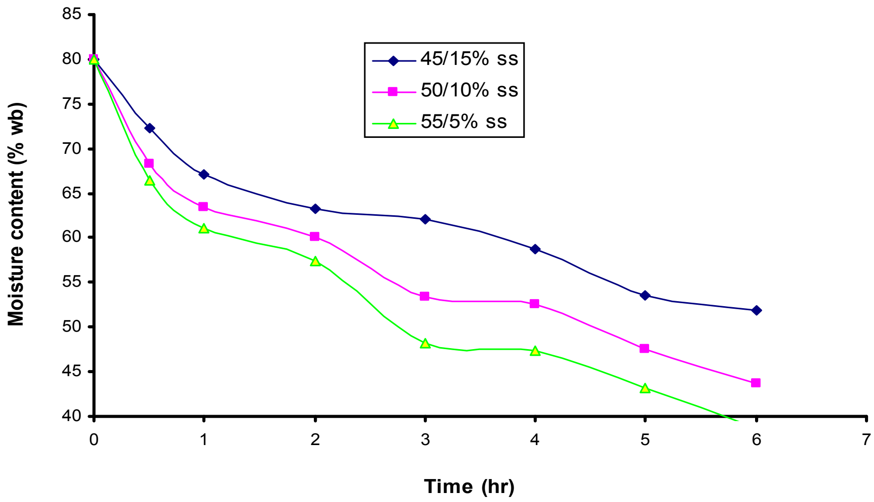

Fig.3.6 Change of moisture content of ginger slices with time in different sucrose/salt solution

3.5 Effect Of Sucrose Solution Concentration And Time On Percent Water Loss And Percent Solid Gain

Effect of sucrose solution concentration (40, 50 and 60%) on percent water loss and solid gain at different time of 5 mm thick ginger slices is shown in Fig.3.7. It is seen from the figure that as percent sucrose concentration increased, the percent water loss is (WL) also increased. Simultaneously, percent solid gain (SG) increased with increasing percent sucrose concentration but comparatively %WL is quite higher than % SG at the similar concentration of sucrose. It is also seen that the %WL and % SG also increased with increasing immersion time at similar concentration. This behavior is in agreement with Islam and Flink, (1982); Hawkes and Flink, (1978) ([11], [7]). Fig.3.8 showed similar behavior of solution concentration with water loss and solid gain for combined sucrose and/or salt solutions.

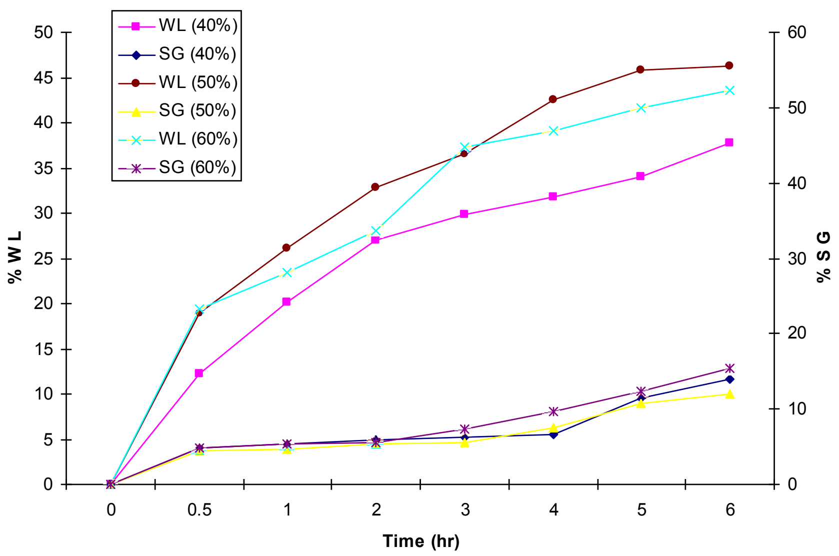

Fig.3.7 Water loss and solid gain of ginger slices with time in different concentration sucrose solution

In this study it is also observed that %WL and % SG and thus also NSC increased with increase in concentration of solute. This is supposed since the solute and water activity gradient increased with increasing solute concentration. Several other researchers ([11], [7], [9]) also showed that increase in concentration of sucrose gave increased amount of water loss and solid gain.

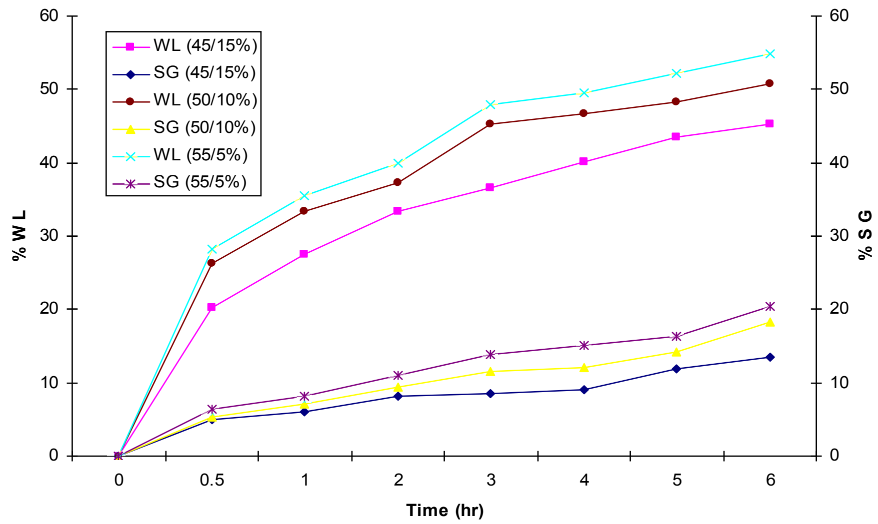

Fig.3.8 Water loss and solid gain of ginger slices with time in different concentration sucrose/salt solution

The results from Fig. 3.7, 3.8, 3.9, 3.10 and 3.11, showed that for total similar solution concentration, %WL was nearly the same for sucrose or sucrose and salt solution, while % SG was quite high for sucrose/salt solution, thus NSC also increased when compared with similar concentration of sucrose. As for example, 60% sucrose osmosed sample for 6 hrs gave 52.24% WL, 15.38% SG and 2.88 NSC and of 55/5% sucrose/salt sample osmosed for 6 hrs gave 54.86% WL, 20.35% SG and 3.11 NSC. A simple calculation showed that for 55/5% sucrose/salt osmosed ginger gave 1.06 times higher %WL, 1.31 times higher %SG and 1.12 times higher NSC than those of 60% sucrose osmosed product.

3.6 Effect Of Sucrose Solution Concentration On Normalized Solid Content (NSC)

To find out the effect of solution concentration on NSC, experiments were conducted with 40, 50 and 60% sucrose solution for periods of ½, 1, 2, 3, 4, 5 and 6 hrs and data were analyzed as per method of Hawkes and Flink (1978) [7]. NSC data versus concentrations were plotted and shown in Fig.3.7. It is observed that increase in sucrose concentration gave increased NSC and a linear relationship was obtained:

NSC = 0.034C+0.8267 (For 6 hrs, C = sucrose concentration) (9)

From the above equation it is indicated that higher concentration of sucrose in osmosis solution gave increased NSC at a given time. It is obviously understandable since the higher the concentration, the higher is solute and water activity gradient ([10], [12], [7]).

The45/15, 50/10 and 55/5% 45/15, 50/10 and 55/5% sucrose/salt osmosed ginger showed that increased sucrose concentration in the combined 60% sucrose/salt solution gave increased NSC (Fig.3.9). The highest NSC was given by 55/5% sucrose in the combined sucrose/salt solution was linear.

The relationship is NSC = 0.26 C +2.42 (For 6 hrs. C = sucrose/salt concentration) (10)

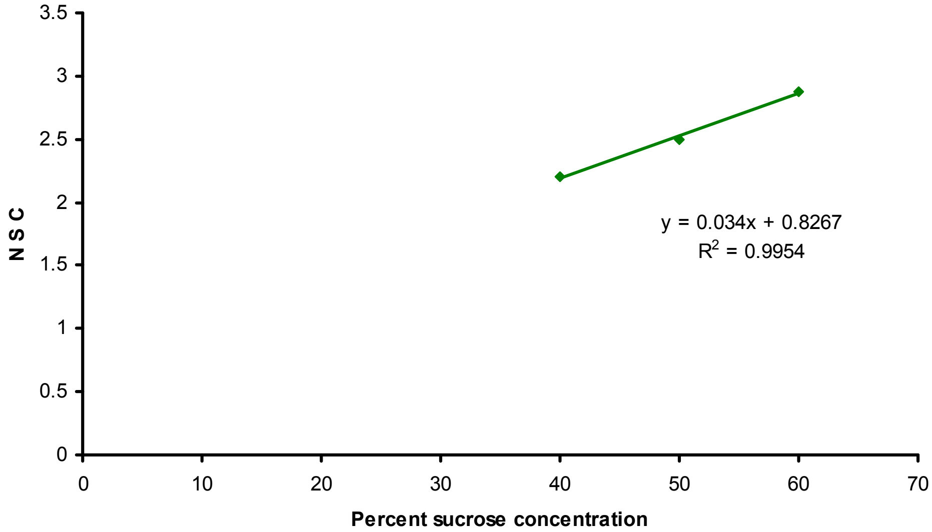

Fig.3.9 Effect of sucrose solution concentration on NSC of ginger slices

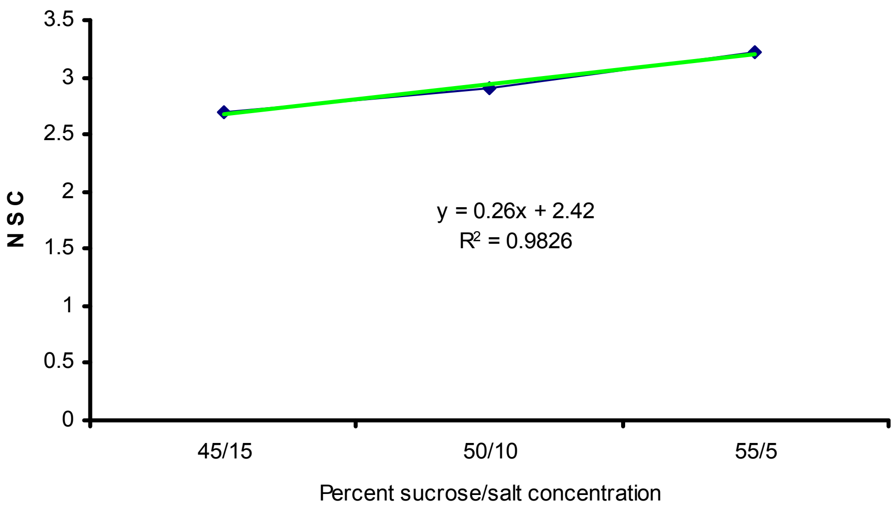

Fig. 3.10 Effect of sucrose/salt solution concentration on NSC of ginger slices

Uddin (2001) [20] also found that the highest NSC was given by 55/5% sucrose/salt solution compared to 45/15% sucrose/salt and 50/10% sucrose/salt osmosed papaya. But this behaviour is inconsistent to earlier findings by Islam (1980) [10] who found that 45/15% sucrose/salt osmosed potato gave the highest NSC (3.94) as compared to 50/10% sucrose/salt osmosed potato who mentioned that increased salt in combined sucrose/salt solution of same total concentration results in increased molar concentration with resultant increased NSC. The differences of the NSC may be attributed to product's structure, texture and constituents as well as solute's characteristics ([10], [2]).

3.7 Kinetics Of Osmotic Dehydration

From Fig.3.11, it is found that at constant solution concentration increase in immersion time gave increased normalized solid content. The relationship of NSC with square root of time for 60% sucrose and 55/5% sucrose/salt osmosed ginger are;

$$NSC = 0.0999\sqrt{t} + 0.8886, \text{ where t is in minute} \quad (11)$$

$$NSC = 0.1096\sqrt{t} + 1.0875 \quad (12)$$

The relationship between NSC and time has been derived from theoretical consideration (Fick's diffusion equation) and is justified since osmotic dehydration is a two-way diffusion process and diffusional concentration is time dependent ([12], [7]).

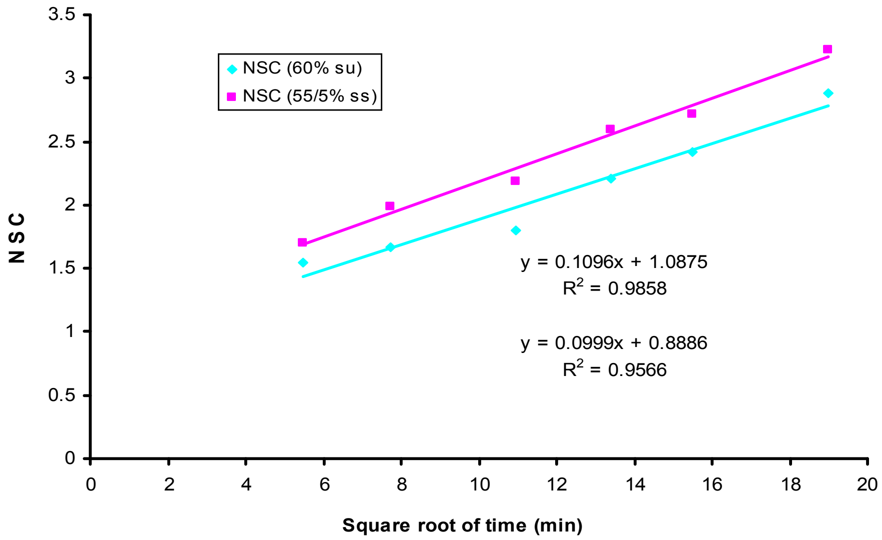

Fig.3.11 Effect of square root of time on normalized solid content for 60%sucrose & 55/5%sucrose/salt solution

From regression equation 11, it was seen that the mass transfer value (K-value) were 0.0999 and 0.1096 for 60% sucrose osmosed and 55/5% sucrose/salt osmosed respectively. It is remarkable that K-value is higher for 55/5% sucrose/salt solution is more effective than 60% sucrose/salt osmosed product due to higher molar concentration of 55/5% sucrose/salt osmosed product.

4 Conclusion

The rate of drying depends on air velocity, temperature, thickness etc. Drying time of ginger to a specific moisture ratio (eg. MR=0.1) increases with increase in sample thickness, while the rate constant has a power law relationship with thickness and the value of index of the equation is quite below 2 indicating presence of significant external resistance to mass transfer and increased airflow resulted in higher drying rate. Among 6 different solution concentration/types tested, the three top most solutions concentrations/types are 55/5 sugar-salt, 50/10 sugar-salt, and 60% sugar giving 3.22, 2.90 and 2.88 NSC for 6hr osmosis; though higher NSC is desirable for higher product throughput, the %WL and %SG could be crucial in the choice of solute type concentration with respect to stability related to depression of a_w taste and cost of solute(s). The developed equations based on Fick's law for different solution concentration/types, thickness of ginger slices and solution temperature and Arrhenius equations together with data on %SG and %WL could be advantagegeously used to develop cost-effective, good quality dehydrated ginger by using mechanical dryer as osmotic dehydration alone does not result in shelf stable product

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