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Research Paper

Osmo-convective Drying Kinetics of Pineapple Cubes and their Quality Evaluation

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ABSTRACT

Osmotic dehydration kinetics of pineapple cubes (10 mm × 10 mm × 10 mm) was studied over a range of sugar concentration (40, 50 and 60^{0}B) and soaking temperature (30, 45 and 60^{o}C) of osmotic solution. The cubes were further dehydrated by convective hot air drying at 40, 50 and 60^{o}C. Osmotic dehydration kinetics indicated that both water loss and solids gain increased with increase of syrup soaking temperature and concentration, the former having much more effect for the range of values tested. After the osmotic treatment, the moisture content of fruits and vegetable are usually reduced by 316.24-399.54 (%db). The effect of drying conditions (air temperature) on the osmo-convective dehydrated pineapple cubes on of dried product quality (TSS, pH, acidity, reducing sugar, non-reducing sugar, total sugar) was also evaluated. The drying took place in the falling rate period. The drying rate decreases with the decreases in the moisture content and it reaches to zero at the final moisture content of the osmo-convective dried of pineapple cubes. The Hendersons and Pabis Model was well fitted to the experimental data $r^2 \geq 0.753$. The effective diffusion coefficients for water and solute diffusion were determined, considering pineapple as slab thickness 1 cm. The effective diffusion coefficients for water as well as solute were empirically correlated with sugar concentration, soaking temperature and convective hot air temperature. The effective diffusivity was found to be in the range of 6.301×10^{-8} to 3.4635×10^{-7} m^2/s. The activation energy for pineapple cubes, which was estimated by using Arrehenius equation was be in the range 220.39 to 278.84 kJ/mole. Overall score of sensory characteristics ranged from 6.3 to 8.7 for all drying temperature. The quality characteristics of dried pineapple cubes i.e. TSS, pH, acidity, Reducing sugar, Non-reducing sugar, total sugar were significant at $p \leq 0.05$. The best sample of pineapple cubes was, the cubes soaked at 60^{o}B sugar concentration and exposed to 60°C resulted the best sensory score and the quality characteristics are as follows TSS 32.42%, P^H 4.53%, Acidity 0.651%, Reducing sugar 19.09%, Non-Reducing sugar 41.79% and Total sugar 60.87% respectively.

Keywords: Pineapple, Osmotic dehydration, convective drying, Drying rates

Pineapple (*Ananas comosus*) is an important economic fruit of tropical areas with the top world producers being Thailand, Philippines, Brazil, Indonesia, Costa Rica, China, India, Nigeria, Mexico and Vietnam. India ranks 13th in pineapple production in the world (NHB, 2014). Pineapple has originated from American continent, Brazil and Paraguay (NHB, 2014). Pineapple (*Ananas comosus*) is a fruit produced in most of the countries with wet tropical weather,

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and the total world production in 2013-14 was about 23.61 Million Metric Tonne (NHB, 2014). Brazil is the second largest producer of pineapples in the world (FAO, 2012). India produces of about 1.736 Million Metric Tonne pineapple in 2013-14, and the export of pineapple from India was 3567 Metric Tonne (NHB, 2014).

Pineapple is rich source of antioxidants and vitamins that play a key role in health promotion through fighting of diseases such as cardiovascular disease, cancer. The consumption of pineapple can decrease risk of obesity, cardiovascular diseases, type 2 diabetes, and cancer (Hossain *et al.* 2015). Pineapple has high sugar content and is rich in vitamins A and C, over 70% of the annual production is consumed in the fresh form. Pineapples have a high content of vitamins and are an excellent source of bromelain, an enzyme used as meat tenderizing agent and as a neutraceutical (Lotz-Winter, 1990). The vitamin C content of the pineapple varieties 73-50, 53-116 respectively (Sanewski and Giles, 1997). The increasing production of the fruit and its high perishable nature with lack of facilities for transportation of the produce from the area of production to the customers provide some necessity to transform it into a more stable form.

Dried fruits have higher nutrient density and fibre content, longer shelf life, and significantly higher phenol antioxidant content compared to fresh fruits (Hossain *et al.* 2015). Pineapples are rich in minerals like potassium, sodium, phosphorus, magnesium, sulphur, calcium, iron and iodine. The Giant Kew variety contained 13.3% Total soluble solids (TSS), 8.66% total sugar and 7.4% non reducing sugar. Ascorbic acid value of pineapple in is 21.5 mg/100g-fw. Moisture content of pineapple range from 86.66%. Titratable acidity 2.03 mg/100g and Protein 7.2 mg/100g (Hossain *et al.* 2015).

Although pineapple is one of the most important commercial fruits, due to its very pleasant aroma and flavour (Rattanathanalerk *et al*. 2005), the storage life of fresh pineapples is limited to 1–2 weeks at ambient temperature. Seventy percent of the pineapple produced in the world is consumed as fresh fruit (Loeillet, 1997). However, in many developing countries, only a limited quantity of pineapple products (canned fruit, canned juice or frozen juice concentrate) are produced. During peak season of harvest, as a consequence of long distances between production zones and consumers and inadequacy of refrigeration facilities, considerable quantities of fruit can be wasted.

Consumer demand has increased for processed products that keep more of their original characteristics. Drying is one of the most common methods of food preservation for a long time (Sagar and Suresh Kumar, 2009). Low cost technologies for producing locally and globally consumable commodities need to be developed to encourage fruit and vegetable processing at home scale, cottage and small scale levels. Drying is a well-known preservation method because water removal and lower water activity reduce the risk of microbial development, and dried fruit can be stored and transported at a relatively low cost (Lenart 1996; Lin *et al.* 1998).

Osmotic dehydration is widely used for the partial removal of water from plant tissues by immersion in a hypertonic solution i.e. 40, 50, 60 and 70^{0}B etc. The diffusion of water is accompanied by the simultaneous counter diffusion of solutes from the osmotic solution into the tissue. Since the membrane is responsible for osmotic transport is not preferably selective, other solutes present in the cells can also be leached into the osmotic solution (Giangiacomo *et al*. 1987; Torregianni, 1993; Rastogi and Raghavrao, 1995; Alvarez., 1995; Rastogi *et al.* 2002). The rate of diffusion of water from any material made up of such tissues depends upon factors such as temperature and concentration of the osmotic solution (Marcotteand and Le Maguer, 1992; Roult-Wack *et al.* 1992), temperature, size and geometry of material (Suresh Kumar *et al.* 2006) the solution to material ratio (Lerici *et al*. 1985).

The use of the osmotic dehydration process in the food industry has several advantages: quality improvement in terms of color, flavor, and texture, energy efficiency, packaging, distribution and cost reduction, no chemical pre treatment, provide required product stability and retention of nutrients during storage (Rahman and Perera, 1999; Raoult-Wack, 1994). Nevertheless, a loss of acids, vitamins, polysaccharides and minerals, which flow from the fruit to the osmotic solution, has been observed (Co´rdoba, *et al.* 2003; Garcı´a-Martı´nez *et al*. 2002; Peiro, Dias,Camacho, and Martı´nez-Navarrete, 2006; Uzuegbu and Ukeka, 1987). This dehydration step generally does not produce product of low moisture content having long shelf life and stability. To get relatively stable product the technique should complement with other drying methods like; convective, freeze, microwave or vacuum drying steps. This dehydration method it also increases sugar to acid ratio, improves texture and stability of the pigment during dehydration and storage (Raoult-Wack, 1994).

The osmotic drying (Yao and Le Maguer, 1994), can be used as a pre treatment before air drying in order to reduce the water content of the food by 30 and 70% of the original amount (Lenart and Lewicki, 1988). Only osmotic dehydration will usually not give rise to sufficiently low moisture content for the product to be considered shelf-stable (Rahman and Lamb, 1991). It is effective even at ambient temperature, the heat damage to texture, colour and flavour of food are minimized (Torregginni, 1993). OD can remove up to 50% (Rastogi and Raghavararo, 1997) of the water in the original fruits or vegetables. However a longer contact time of the samples with the sugar solution gives a higher solids gain and a higher moisture loss (Nieuwenhuijzen *et al*. 2001). The osmotic dehydration characteristics of pineapple is very important in the design operation and control of the industrial dryer. The rate of dehydration is usually controlled by moisture transport (diffusion) within the product and physical structure of the fruit.

Pre-drying treatment such as osmotic dehydration (OD) before conventional hot air drying, reduces the energy consumption and improve food quality (Torreggiani 1993; Sereno *et al.* 2001). In fruit, the usual osmotic dehydration agents are aquatic solutions of low-molecular weight pure sugars, or mixtures with corn syrup, etc are used. The interest in introducing the osmotic dehydration process into a conventional stabilizing process has two main objectives; quality improvement and energy savings (Ponting *et al.* 1966; Dixon and Jen,1977; Heng *et al.* 1990; Lewicki and Lenart, 1992). Osmotic dehydration preceding air drying preserves fruits and vegetables from some colour changes and increases the retention of flavour during the drying process (Lenart and Lewicki, 1988); prevents oxidative browning and/or loss of volatile flavouring constituents; reduces the fruit acidity. (Ponting, 1973); and minimize the energy demand required in the overall drying process. However, Matusek and Meresz (2002), Singh (2001) and Torringa *et al.* (2001) have reported that osmotic dehydration spectacularly shortened the total convective drying time. Air drying following OD was studied in strawberries (Alvarez *et al.* 1995), pears (Ertekin and Cakaloz 1996; Park *et al.* 2002), apples (Nieto *et al.* 1998; Mandala *et al.* 2005), mangos (Nieto *et al.* 2001) and papayas (El-Aouar *et al.* 2003).

In the present work an attempt has been made to dry the pineapple cubes by osmo-convective drying, the quality of the dehydrated product is also studied.

THEORETICAL CONSIDERATIONS

Osmotic dehydration

1. Water loss (W_L)

Water loss is the quantity of water lost by pineapple cubes during osmotic processing. The water loss (WL) is defined as the net weight loss of the fruit on initial weight basis and was be estimated by equation (1) (Lenart and Flink 1984; Shi *et al.* 1995; Silveira *et al.* 1996 and Kaleemullah *et al.* 2002).

$$W_L = \frac{W_i . X_i - W_\theta . X_\theta}{W_i} \quad ...(1)$$

Where,

W_θ = mass of cube after time θ, *g*

W_i = initial mass of cube, *g*

X_θ = water content as a fraction of mass of cube at time θ.

X_i = water content as a fraction of initial mass of cube, fraction

2. Solid gain

The solids from the osmotic solution get added to the samples during osmotic dehydration. The loss of water from the sample takes place in osmotic dehydration consequently it increases the solid content. The solid gain is the net uptake of solids by the pineapple cubes on initial weight basis (Lenart and Flink (1984); Shi *et al.* 1995; Silveira *et al.* 1996 and Kaleemullah *et al.* 2002) The solid gain was calculated using expression (2).

$$SG = \frac{W_\theta(1-X_\theta) - W_i(1-X_i)}{W_i} \times 100 \quad ...(2)$$

Where,

SG = solid gain (g per 100 g mass of sample).

W_θ = mass of slices after time θ, g

W_i = initial mass of slices, g

X_θ = water content as a fraction of mass of slices at time θ.

X_i = water content as a fraction of initial mass of slices, fraction

3. Mass reduction

The overall exchange in the solid and liquid of the sample do affect the final weight of the sample. The mass reduction (MR) can be defined as the net weight loss of the fruit on initial weight basis (Silveira *et al.* 1996).

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

Where,

W_θ = mass of slices after time θ, *g*

W_i = initial mass of slices, *g*

MR = Mass reduction

Drying Characteristics

Moisture Content (% db) versus drying time (min) and drying rate (kg of water removed/kg of dry matter/h) with respect to moisture content (%db) was determined for drying of pineapple cubes. Moisture ratio versus drying time (min) was also determined from the experimental data of pineapple cubes.

1. Drying rate

The moisture content data recorded during experiments were analyzed to determine the moisture lost from the sample of pineapple cubes in particular time interval. The drying rate of sample was calculated by following mass balance equation (Brooker *et al.* 1974).

$$R = \frac{\text{WML (kg)}}{\text{Time interval (min)} \times \text{DM (kg)}} \quad ...(4)$$

Where,

R = Drying rate at time θ

WML = Initial weight of sample – Weight of sample after time θ

DM = Dry matter of the sample, *g*

2. Moisture Ratio

By comparing the phenomenon that drying takes place in falling rate period, with Newton's law of cooling, the drying rate is proportional to the difference in moisture content between the material being dried and equilibrium moisture content at the drying air condition as given in equation (5);

$$MR = \frac{M - M_e}{M_0 - M_e} \quad ...(5)$$

Where, *MR* = Dimensionless moisture ratio,

M = Moisture content at time t (% db),

M_0 = Initial moisture content (% db),

M_e = Equilibrium moisture content (% db).

Evalution of the model

In most of the studies carried on drying, diffusion was generally accepted to be the main mechanism during the transport of the moisture to the surface to be evaporated. The solution of ficks equation, with the assumption of moisture migeration being by diffusion negligible shrinkage, constant diffusion coefficients and temperature and for a slab (Crank, 1975; Pala *et al.* 1996);

$$MR = \frac{M-M_e}{M_0-M_e} = \sum_{n=1}^{n=r} \frac{8}{(2n-1)\pi^2} \exp\left(-\frac{D_{eff}(2n-1)^2\pi^2.t}{(4L)^2}\right) \quad \ldots(6)$$

Where,

M_0 = Initial moisture content (%db)

M_e = Equilibrium moisture content (%db)

L = Half thickness of slab

n = Positive integer

The Henderson and Pabis model is first solution of Ficks second law (Henderson and Pabis, 1961, Ozdemir and Devres, 1999);

$$MR = \frac{M-M_e}{M_0-M_e} = \frac{8}{\pi^2}\exp\left(-\frac{\pi^2 D_{eff}\,t}{4L^2}\right) \quad \ldots(7)$$

Equation (3.7) can be written in a more simplified form as;

$$\frac{M-M_e}{M_0-M_e} = k.\exp(-ct) \quad \ldots(8)$$

Where,

k = constant

c = Drying constant

D_{eff} = Effective moisture transfer diffusion coefficient, m^2/s

1. Calculation of moisture diffusivity and activation energy for convective hot air drying

The plot of ln MR versus time gives a straight line with a slope of;

$$\text{Slope} = \frac{\pi^2.D_{eff}}{4L^2} \quad \ldots(9)$$

Activation energy (E_a) was calculated using Arrhenius equation (s). The logarithm of D_{eff} versus a reciprocal of absolute temperature (T_a) was plotted which resulted in a linear relationship between (ln D_{eff}) and ($1/T_a$). The activation energy of diffusion was estimated by using following equation (Doymaz *et al.* 2011);

$$D_{eff} = D_0.\exp\left(-\frac{E_a}{R.T_a}\right) \quad \ldots(10)$$

Where, D_0 = diffusivity constant or Arrhenius pre-exponential factor (m^2/s),

E_a = activation energy (kJ/mol),

R = universal gas constant (kJ/ mol k),

T_a = Absolute temperature (K)

$K_1 = \exp(-\frac{E}{RT})$

MATERIALS AND METHODS

Osmotic dehydration of pineapple cubes

Ripe pineapple fruits of Gaint Kew variety were procured from the local market. Fully ripe, medium sized fruits, with soluble solid content from 11-13±1^{0}Brix, were used in these experiments. The fruits were washed, hand peeled, cut into cubes of size 10mm×10mm×10mm. Pineapple cubes (2 kg) were imersed in beakers containing sugar solution 40, 50, 60^{0}Brix, the solution were maintained at 30, 45, 60°C respectively in hot water bath. Fig. 4.2 shows the hot water bath. The syrup to fruit ratio was 2:l (w/w) to limit the concentration changes due to uptake of water and loss of solute to the cubes. Osmotic dehydration done at 3 levels of sugar syrup concentrations and 3 levels of soaking temperatures at 40, 50, 60 ^{0}Brix and at 30, 45, 60°C respectively. The experiments were repeated thrice, the total number of experiments were 27. The mass reduction w.r.t. time were recorded at each 10 minutes interval. The observations recorded were solid gain w.r.t. time, water loss w.r.t. time and mass reduction w.r.t. time. The observations were recorded till the constant reading was observed, it varied from from 30 to 140 min for all the treatments. After expose sample to osmosis the surface moisture from the sample was removed by using tissue paper.

Convective drying of osmotically dried pineapple cubes

Experimental setup

Osmotically dried pineapple cubes as discussed in the earlier section were dried in the convective hot air dryer at 40, 50, 60^{0}C ±1^{o}C. The drying was carried out in a tray dryer (Make: M/s Rotex Industries, Pune) having capacity 60 kg. There were 24 no. of perforated trays inside the tray dryer. The size of the tray was 54 cm × 50 cm × 2 cm. The temperature of the drying was kept as 40, 50 and 60±1 ^{0}C. The pineapple cubes were dried in a thin layer drying. Pineapple cubes loaded in the dryer when the dryer attain 40±1 $^{\circ}$C set point temperature. Air velocity was fixed at 2 m/s. There were two heaters of 1.5 kW having total power 3 kW. The weight loss during drying was measured by three number of perforated trays placed at three different locations in tray dryer i.e. top, middle and lower side of the dryer. The Initial moisture content of the pineapple cubes was calculated by using hot air oven as per AOAC, 2010.

$$\text{Moisture Content (db)\%} = \frac{W_1 - W_2}{W_2} \times 100 \quad \ldots(11)$$

Where,

W_1 = weight of sample before drying, *g*

W_2 = weight of bone dried sample, *g*

The weight loss was recorded by an electronic balance (Make: M/s Contech Instruments, Navi Mumbai; Model: CT-3K1) with an accuracy of 0.001 g. The weight loss of the pineapple cubes were recorded at 10 min interval initially up to 1 hours, after at 30 min interval up to 3 hours and then 1 hour interval during progression of drying till the constant weight has achieved. The moisture content versus drying time, Drying rate versus moisture content and moisture ratio versus time was determine.

Quality evaluation of Osmo-convective dried pineapple cubes

TSS, pH, acidity, reducing sugar, non-reducing sugar, total sugar, moisture content were determined by using standard procedures (Ranganna, 1986) at all three temperature 40, 50 and 60°C and at magnetron ON/OFF time in sec 15s/30s, 20s/30s and 25s/30s of dried pineapple cubes. Three replications of each test were carried out at each temperature.

1. Total soluble solids (TSS)

The TSS of Osmo-convective and osmo-microwave vacuum dried pineapple cubes were measured by using digital refractometer (Make: Atago, Japan). The prism of the refractometer was cleaned with the help of distilled water and tissue paper. The distilled water was used to calibrate the Refractometer, the TSS of distilled water is zero and is known. This was used as standard for calibration. The Osmo-convective and osmo-microwave vacuum dried pineapple cubes were grounded and small quantity water was added to it. A drop of the sample was placed on the prism and the TSS of the sample was measured.

2. pH

pH was recorded by digital pH meter (Make: Hanna Instruments, Model: pH 211). The equipment was standardized by 4 and 7 pH standard solution. The pH of dried pineapple cubes was determined by adding 15 ml of distilled water to 5 g of ground pineapple powder.

3. Acidity

Acidity was determined by using titration method (Ranganna, 1986). 1g of ground dried pineapple powder was taken. 20 ml distilled water was added to it. Pipette out 1 ml of this sample in conical flask and 100 ml distilled water was added to it. 2-3 drops of phenolphthalein indicator was added to it. The solution was titrated with 0.1 N NaOH. End point is faint pink colour. Acidity was calculated by using equation,

Total Acid, % =

$$\frac{B.R.\times Normality \times Vol.madeup \times equivalentwt.of acid \times 100}{vol.of sampletakenforestimation \times wt.of sample \times 1000} \quad \ldots(12)$$

4. Reducing Sugar

Reducing sugar was estimated by Fehling's method (Ranganna, 1986). The process was carried out in three steps. In first part, 5 g dried ground pineapple cube powder was added with 100ml distilled water. 2-3 drops of phenolphthalein indicator was added to it. This sample solution was titrated with 1 N NaOH. The end point was feint pink colour. It was filtered after addition of lead acetate and potassium oxalate solution. In second part, Fehling solution A, B and distilled water were taken in proportion 1:1:1 in a conical flask, and in the third part, titration of first part solution against second part solutions was carried out by using methylene blue indicator in boiling condition. Titration was continued until the end point of brick red colour appears. Reducing sugar was calculated by using formula:

$$\text{Reducing Sugar,\%} = \frac{\text{mg of invert sugar} \times \text{Dilution} \times 100}{\text{Titration} \times \text{Wt. or volume of sample} \times 100} \quad \ldots(13)$$

5. Non reducing sugar

Non reducing sugar was determined as per the Ranganna, 1986. In this method, part one solution of reducing sugar was used. 50 ml of this solution was neutralized with concentrated 20 N NaOH after overnight keeping with 1:1 HCL. By making 100 ml volume with distilled water, this solution was titrated with part two solutions i.e. first part and second part. In the third part same procedure was followed as discussed in reducing sugar. Total sugar was calculated by using equation,

$$\text{Total Sugar,\%} = \frac{\text{mg of invert sugar} \times \text{Dilution} \times 100}{\text{Titration} \times \text{Wt. or volume of sample} \times 100} \quad \ldots(14)$$

Non reducing sugar was calculated by using equation,

$$\textit{Non Reducing Sugar, \%} = \textit{Total sugar, \%} \times 0.95 \quad \ldots(15)$$

Statistical analysis of quality characteristics of dried pineapple cubes

Statistical analysis of SE and CD values for quality characteristics of dried pineapple cubes like TSS, pH, acidity, Reducing sugar, Non-reducing sugar, total sugar were determined and was carried out by SAS 3.0. Recorded data were subjected to statistical analysis by "Analysis of variance" technique. ANOVA with replicated factor was done. The significant and non-significant treatment was judged with the help of F (variance ratio) table and t-test. The significant different between the means was tested against the critical difference at $p \leq 0.05$.

Sensory evaluation of Osmo-Convective dried pineapple cubes

The sensory evaluation was carried out using trained taste panel consisting of students and staff from the College of Agricultural Engg. and Tech., Dapoli. The number of panelists who evaluated Osmo-Convective dried products was 43 (23 female and 20 male). Samples were coded using random code A to AA (27 samples). Samples were coded using random code A to AA (27 samples). Panelists were served with salted potato chips, water to break the monotony in taste of the dried pineapple cubes.

Mean sensory scores for quality attributes (colour, taste, texture, flavour) and overall acceptability were recorded in individual sheet and average scores are reported. The sensory method employed a nine-point hedonic scale used to assess colour, flavour, taste and texture: 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), 1 (dislike extremely). These samples for each treatment were placed in the paper dish. These samples were organoleptically tested for different quality attributes like colour, texture, taste, flavour and overall acceptability.

Statistical analysis of sensory evaluation

ANOVA with replicated factor for sensory analysis was done. The significant and non-significant treatment was judged with the help of F (variance ratio) table and t-test. The significant different between the means was tested against the critical difference at $p \leq 0.05$.

Optimum product quality based on sensory score

Drying of pineapple cubes 3 levels of sugar concentration 40, 50, 60^{o}Brix, soaking temperature 3 levels at 30, 45, 60^{o}C, dried by the convective hot air dryer at 40, 50 and 60^{o}C were evaluated for better sensory scores and retention of nutritional quality characteristics (i. e. TSS, pH, acidity, Reducing sugar, Non-reducing sugar, total sugar), considering the all above properties the best treatment was decided.

RESULTS AND DISCUSSION

Osmotic Dehydration of pineapple cubes:

The fully riped pineapple cubes (10mm×10mm×10mm) were having initial moisture content (649.52%db). These cubes exposed at 40, 50 and 60^{0}B sugar solution and 30, 45 and 60^{o}C soaking temperatures.

1. Mass Reduction

Fig. 1 shows the typical average % mass reduction of pineapple cubes w.r.t. time (minutes) curve at soaking temperature 30, 45 and 60^{0}C respectively at 40^{0}B sugar concentration. As the soaking temperature increases from 30 to 60^{0}C, the mass reduction (%) increases and it becomes stable reading, after which even the time of exposition increases the mass reduction (%) remains unchanged. The average % mass reduction at 40^{0}B sugar concentration was 6.66, 10.66 and 12.00% at 30^{0}C, 45^{0}C and 60^{0}C soaking temperature respectively. Similar type of behavior has been observed at 50^{0}B and 60^{0}B sugar concentration (trends not shown) at 30^{0}C, 45^{0}C and 60^{0}C soaking temperature. Table 1 shows the peak mass reduction (%) with respect to soaking temperature (or) and time of soaking of pineapple cubes.

From Table 1 it is revealed that as the sugar concentration increases from 40^{0}B to 60^{0}B the mass reduction (%) increases from 6.66% to 17.33% at 30^{0}C soaking temperature. Similarly as the 10.66%

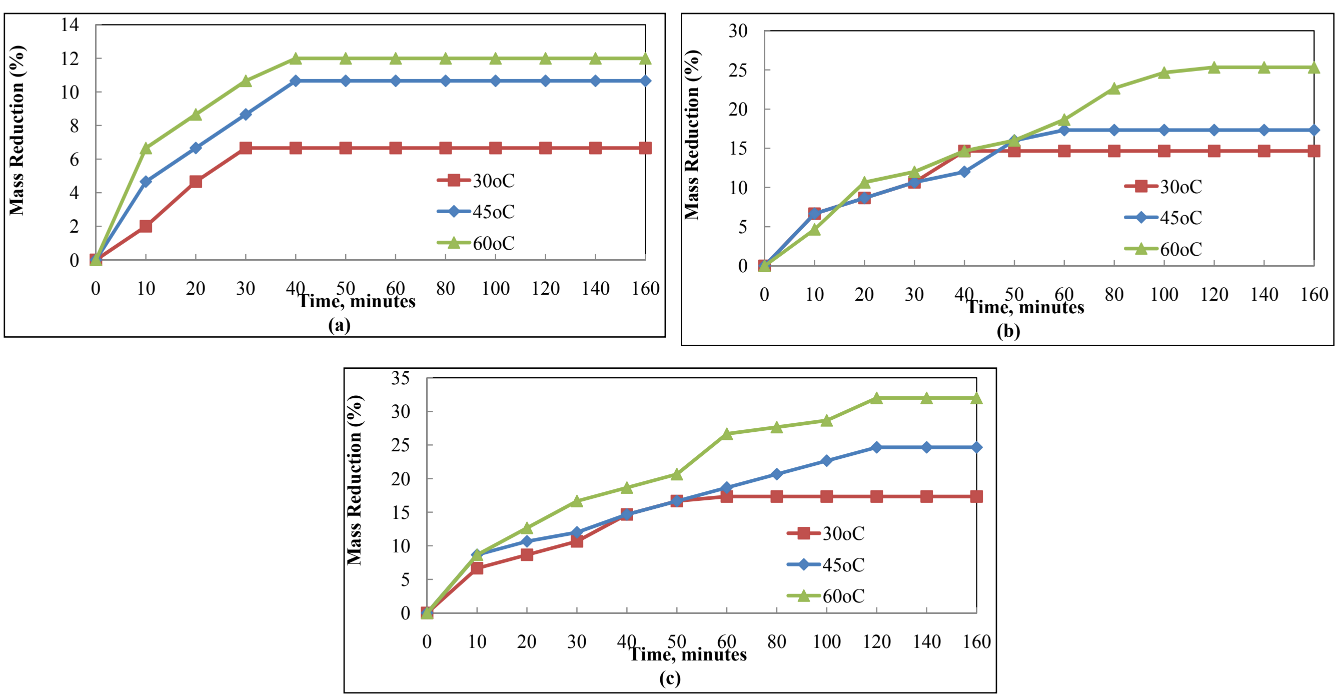

Fig. 1: Mass Reduction (%) versus time (min) at soaking temperature of pineapple cubes at 30, 45, 60^{o}C in sugar concentration (a)40^{o}B; (b)50^{o}B; and (c)60^{o}B

Table 1: Mass reduction (%) with respect to time at varied sugar concentration

Soaking Temp	Mass reduction % at various sugar concentration					
	40°Brix	Time (min)	50°Brix	Time (min)	60°Brix	Time (min)
30°C	6.66	30	14.66	50	17.33	80
45°C	10.66	40	17.33	80	24.66	100
60°C	12.00	50	25.33	100	32.00	120

Table 2: Solid gain (%) with respect to time at varied sugar concentration

Soaking Temp	Solid gain % at varied sugar concentration					
	40°Brix	Time (min)	50°Brix	Time (min)	60°Brix	Time (min)
30°C	5.6	30	12.5	50	14.32	80
45°C	9.52	40	14.32	80	18.57	100
60°C	10.53	50	18.9	100	21.98	120

to 24.66% at 45^{0}C soaking temperature and 12.00% to 32.00% at 60^{0}C soaking temperature respectively. Filho *et al.* 2015 reported that mass reduction upto 26.38% at sugar concentration 50^{0}B and soaking temperature 40^{0}C in pineapple, Correa *et al.* 2014 reported that mass reduction in pineapple 7.4, 8.0 and 13.6 for varied sugar concentration 40, 50 and 60^{0}B respectively. This increase in mass reduction (%) due to increase in soaking temperature. The increase in mass reduction (%) w.r.t to increase in sugar concentration.

2. Solid Gain

Fig. 2 represents the typical curve for solid gain (%) w.r.t. time in minutes of osmotic drying of pineapple cubes at 40^{0}B sugar concentration and soaking temperature 30, 45 and 60^{0}C. As the soaking temperature increases from 30^{0}C, 45^{0}C and 60^{0}C, the solid gain (%) increases 5.6, 9.52 to 10.53% and it becomes stable solid gain (%), after which even the time of exposition increases the solid gain (%) remain unchanged. Similar type of behavior has been observed (trend not shown) at 50^{0}B and 60^{0}B sugar concentration. Table 2 shows the peak solid gain (%) w. r. t. soaking temperature at the time of soaking of the pineapple cubes.

From Table 2 it is reveled that as the sugar concentration increases from 40^{0}B to 60^{0}B the solid gain (%) increases from 5.6% to 14.32% at 30^{0}C soaking temperature. Similarly at 45^{0}C soaking temperature the solid gain (%) increases from 9.52% to 18.57% and for 60^{0}C soaking temperature the solid gain (%) increases from 10.53% to 21.98% respectively. Solid gain (%) increases as the increases in soaking temperature from 30^{0}C to 60^{0}C at each sugar concentration i.e. 40^{0}B, 50^{0}B and 60^{0}B respectively. Similar results have been observed for peas and blueberries products reported in the literature Ertekin and Cakaloz, (1996) and Nsonzi and Ramaswamy, (1998) for respectively. However a longer contact time of the samples with the sugar solution gives a higher solids gain and a higher moisture loss (Nieuwenhuijzen *et al*. 2001). Filho *et al.* 2015 reported that solid gain 7.31% at sugar concentration 50^{0}B and soaking temperature 40^{0}C in pineapple, Correa *et al.* 2014 reported that solid gain in pineapple 6.8, 5.4 and 8.9% for varied sugar concentration 40, 50 and 60^{0}B respectively. Azuara *et al.* 1996 reported that solid gain in potato and apple 6.61 and 7.93 at 70^{0}B sugar concentration solution. Sridevi and Genitha 2011 and Devi *et al.* 2012 reported that solid gain in pineapple was 8.57% at 30^{0}C soaking temperature and 40^{0}B sugar solution. Suresh kumar and Genitha, 2011 reported that solid gain in pineapple slices was 10.5% at 35^{0}C soaking temperature and 50^0 Sugar concentration.

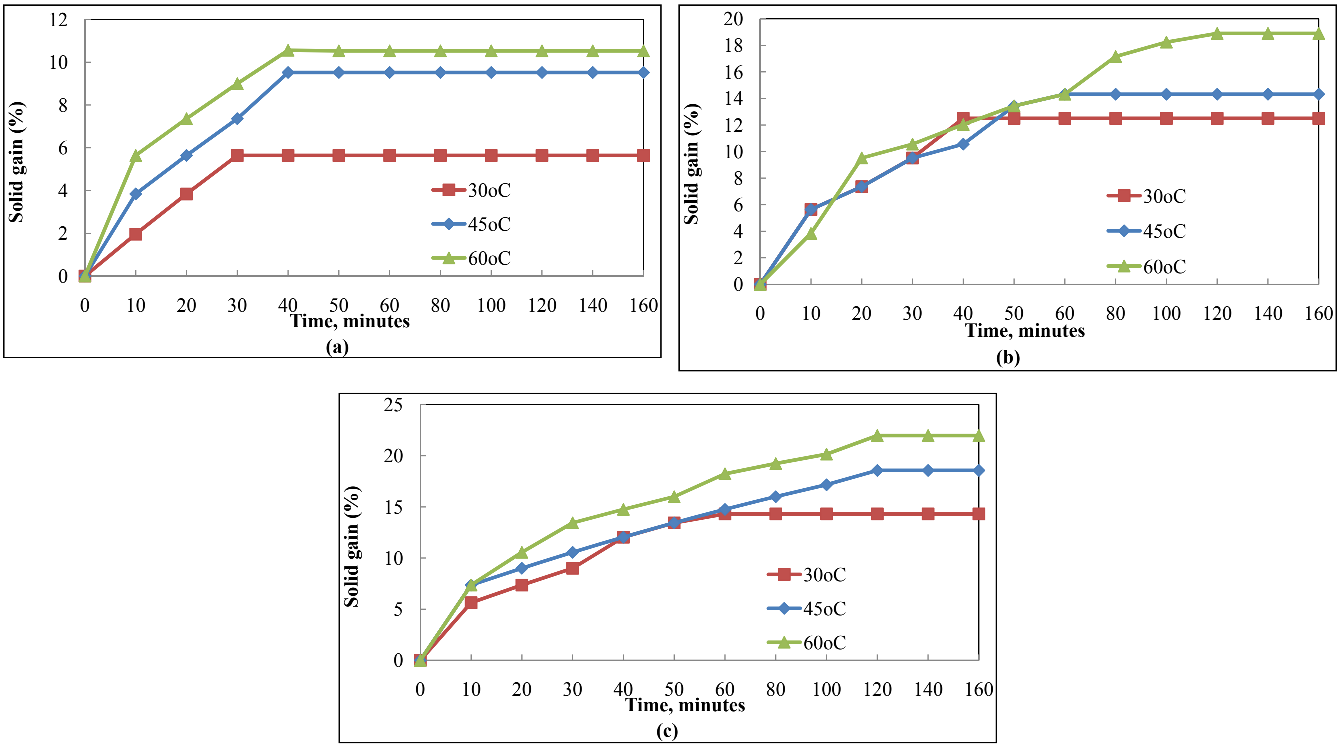

Fig. 2: Solid gain (%) versus time (min) at soaking temperature of pineapple cubes at 30, 45, 60°C in sugar concentration (a)40°B; (b)50°B; and (c)60°B

Table 3: Water loss (%) with respect to time at varied sugar concentration

Soaking Temp	Water loss % at varied sugar concentration					
	40°Brix	**Time (min)**	**50°Brix**	**Time (min)**	**60°Brix**	**Time (min)**
30°C	10.83	30	25.21	50	29.34	80
45°C	18.75	40	29.34	80	39.94	100
60°C	18.76	50	40.86	100	49.46	120

3. Water Loss

Fig. 3 shows a typical curve of the average water loss (%) w.r.t. time in minutes of osmotic drying of pineapple cubes at 40^0B sugar concentration and soaking temperature 30, 45 and 60^0C. As the soaking temperature increases from 30^0C, 45^0C and 60^0C, the water loss (%) increased from 10.83 to 18.76% and it becomes stable reading after which even the time of exposition increases the water loss (%) remain unchanged. The average water loss (%) was 10.83, 18.75 and 18.76 at 30^0C, 45^0C and 60^0C soaking temperature respectively. Similar type of behaviour has been observed (trend not shown) at 50^0B and 60^0B sugar concentration at at 30^0C, 45^0C and 60^0C soaking temperature. Table 3 shows the water loss (%) w.r.t. soaking temperature at the time of soaking of the pineapple cubes.

From Table 3 it is revealed that for a particular value of soaking temperature at 30^0C the sugar concentration increases from 40^0B to 60^0B the water loss (%) increased from 10.83% to 29.34%. Similarly at 45^0C soaking temperature the water loss (%) increased from 18.75% to 30.94% and for 60^0C soaking temperature the water loss (%) increase from 18.76% to 49.46% respectively. Similarly for a particular value of sugar concentration ^{0}B as the soaking

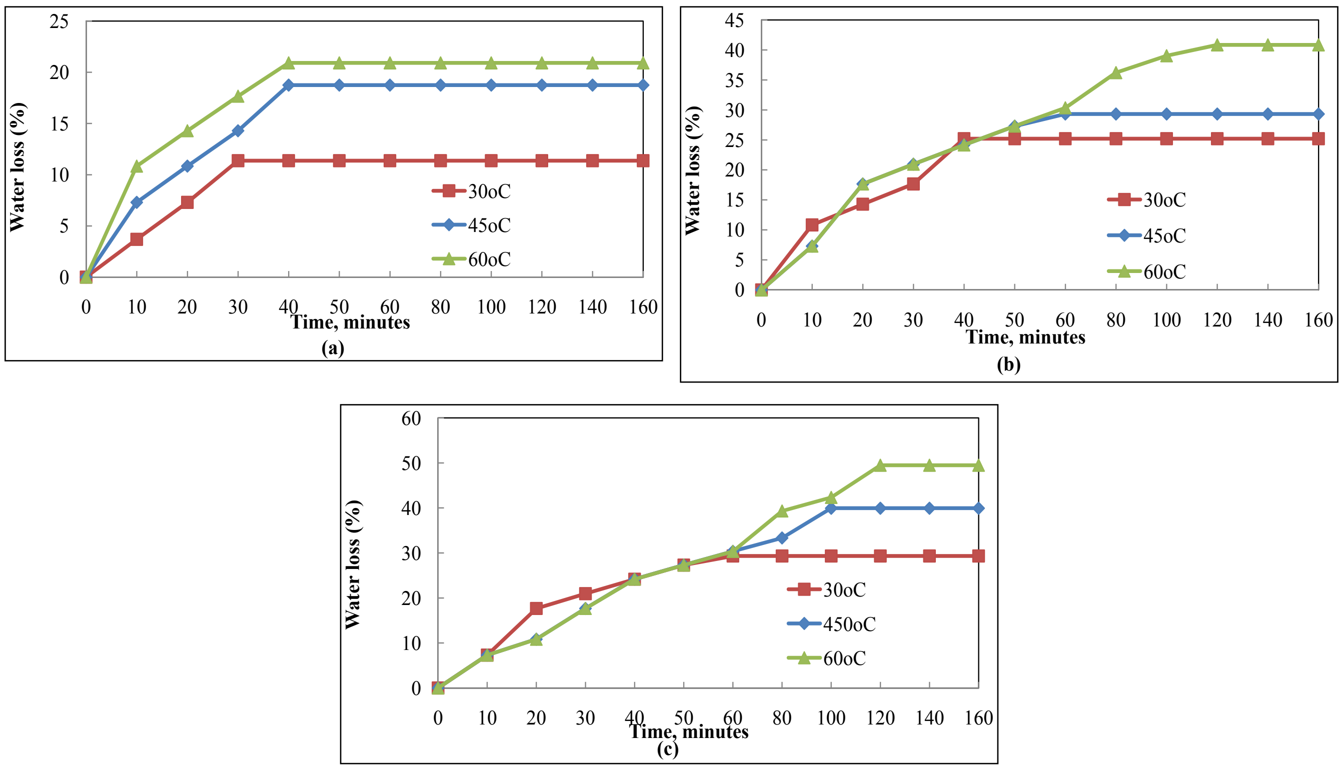

Fig. 3: Water loss (%) versus time (min) at soaking temperature of pineapple cubes at 30, 45, 60°C in sugar concentration (a)40°B; (b)50°B; and (c)60°B

temperature increases from 30 to 60^0C the water loss (%) increased. At 40^0B it was 10.83 at 30^0C and increased upto 18.76%; at 50^0B sugar concentration the water loss (%) increased upto 25.21% and increased upto 40.86% at 60^0B sugar concentration it was 29.34 to 49.46 respectively. Similar kind of results have been reported in the literature for other fruits and vegetable i.e. pea, pineapple, tomato, banana (Ertekin and Cakaloz, 1996; Hawkes and Flink, 1970; Karthanos *et al.*1995; Lazarides *et al.* 1995; Pokharkar and Prasad, 1998). The water loss (%) increased with increase in sugar concentration (^{0}B), it may be due to increased osmotic pressure in the solution at higher concentration, which increased the driving force for water transport. This is in agreement with (Pokharkar *et al.* 1998a; Pokharkar *et al.* 1998b; Nieuwenhuijzen *et al.* 2001). Filho *et al.* 2015 reported that water loss 26.37% at sugar concentration 50^0B and soaking temperature 40^0C in pineapple, Correa *et al.* 2014 reported that water loss in pineapple was 22.4% for at sugar concentration 50^0B. Azuara *et al.* 1996 reported that water loss in potato and apple 69.50 and 70.63% at 70^0B sugar concentration solution. Sridevi and Genitha and Devi *et al.* 2012 reported that water loss in pineapple 21.91% at 30^0C soaking temperature and 40^0B sugar solution. Suresh Kumar and Genitha, 2011 reported that solid gain in pineapple slices 31.3% at 35^0C soaking temperature and 50^0Sugar concentration.

4. Osmotic drying characteristics of pineapple cubes

Fig. 4 shows the typical moisture content (%db) w.r.t. time (min) curve of pineapple cubes dried at soaking temperature 30, 45 and 60^0C in sugar concentration 40^0B. The drying was carried out from an initial moisture content 649.52 (%db) to 399.83 (%db), 316.55 (%db) and 316.55(%db), it took around 40, 50 and 50 minutes to complete the drying process. Similar types of trends have been observed (trends not shown) at sugar concentration 50^0B and 60^0B for drying of the pineapple cubes at soaking temperature 30, 45 and 60^0C. Table 4 shows the final moisture content achieved during osmotic drying of pineapple cubes at sugar concentration 40, 50 and 60^0B and at soaking temperature 30, 45 and 60^0C respectively. It took around 60, 60 and 120 minutes to dry the pineapple cubes from 649.52 (%db) to 257.01(%db), 225.94(%db), 158.57(%db) at 50^0B sugar concentration and at 30, 45 and 60^0C soaking temperature respectively. Also at 60^0B sugar concentration the cubes were dried from 649.52(%db) to 226.01(%db), 163.11(%db) and 120.55(%db) at soaking temperature 30, 45 and 60^0C, the time required for drying was 80, 120 and 120 minutes respectively. It can be clear from the Table 5 that for a particular value of soaking temperature as the sugar concentration increase the final moisture of the cubes was decreased resulting in increased in drying time. Also for a particular value of sugar concentration as soaking time increases the final moisture content of the cubes of the cubes decreases, resulting in drying time. After the osmotic treatment, the moisture content of fruits and vegetable are usually reduced by 30-50% (wet basis) (Yetenayat Bekele and Hosahalli Ramaswamy 2010). It is reported that up to 50% reduction in the fresh weight of fruits or vegetables can be achieved by osmotic dehydration (Rastogi and Raghavararo, 1997).

Fig. 5 shows the typical drying rate (kg of water removed/kg of dry matter/h) of osmotically drying pineapple cubes w.r.t. moisture content (%db) at soaking temperature 30, 45 and 60^0C at 40^oB sugar concentration. The drying rate decreases from 0.402 to 0, 0.287 to 0 and 0.1724 to 0 kg of water removed/kg of dry matter/h at soaking temperature 60, 45 and 30^0C respectively. The higher rate of drying at higher soaking temperature may be due to the fact that the cell permeability increases and increases the rate of osmosis (Pokharkar, 1994). The driving forces have also been increased which may increased the rate of drying of pineapple cubes. Similar types of trends have been observed at sugar concentration 50^oB and 60^oB for drying of pineapple cubes at soaking

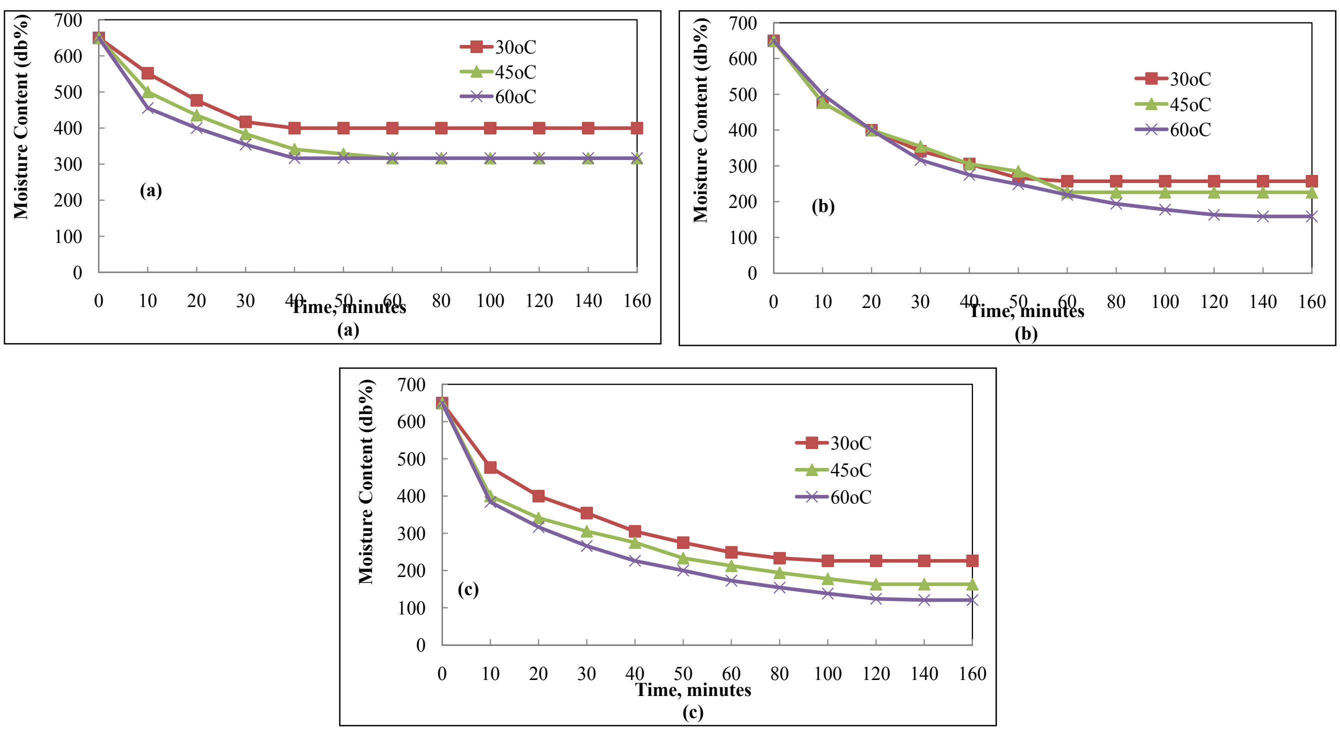

Fig. 4: Moisture content (%db) versus time (min) at soaking temperature of pineapple cubes at 30, 45, 60^oC in sugar concentration (a)40^oB, (b)50^oB and (c)60^oB

Table 4: Final Moisture content (%db) with respect to time at varied sugar concentration and soaking temperature during osmotic drying of pineapple cubes

Soaking Temp	Final Moisture content (%db) at varied sugar concentration					
	40°Brix MC%(db)	Time (min)	50°Brix MC%(db)	Time (min)	60°Brix MC%(db)	Time (min)
30°C	399.83%	40	257.01%	60	226.01%	80
45°C	316.55%	50	225.94%	60	163.11%	120
60°C	316.55%	50	158.57%	120	120.55%	120

Table 5: Drying Rate (kg of water removed/kg of dry matter/h) versus Moisture content (%db) at varied sugar concentration and soaking temperature during osmotic drying of pineapple cubes

Soaking Temp	Final Moisture content (%db) at varied sugar concentration					
	40°B Drying rate	40°Brix MC%(db)	50°B Drying rate	50°Brix MC%(db)	60°B Drying rate	60°Brix MC%(db)
30°C	0.172-0	399.83%	0.287-0	257.01%	0.345-0	226.01%
45°C	0.287-0	316.55%	0.345-0	225.94%	0.514-0	163.11%
60°C	0.402-0	316.55%	0.345-0	158.57%	0.632-0	120.55%

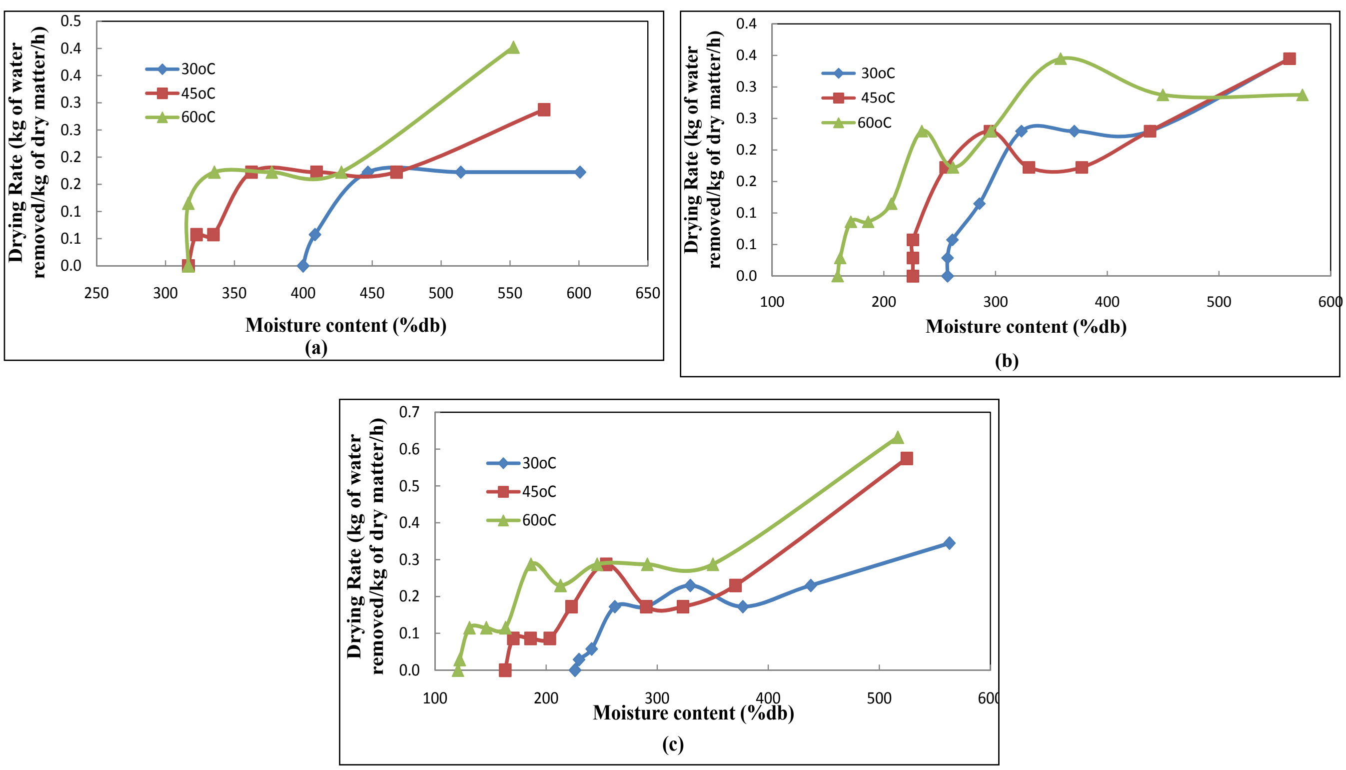

Fig. 5: Drying Rate (kg of water removed/kg of dry matter/h) versus moisture content (%db) at soaking temperature of pineapple cubes at 30, 45, 60°C in Sugar concentration (a)40°B; (b)50°B; and (c)60°B

temperature 30, 45 and 60^{0}C. Table 5 shows the drying rate (kg of water removed/kg of dry matter/h) of pineapple cubes dried osmotically at soaking temperature 30, 45 and 60^{0}C and at 40^{o}B, 50^{o}B and 60^{o}B sugar concentration. At 50^{o}B sugar concentration the drying rate was 0.344 to 0, 0.344 to 0 and 0.287 to 0 at soaking temperature 60, 45 and 30^{0}C respectively. Similarly at 60^{o}B sugar concentration the drying rate was 0.632 to 0, 0.514 to 0 and 0.344 to 0 at soaking temperature 60, 45 and 30^{0}C respectively.

Convective hot air drying of osmotically dried pineapple cubes

The osmotically dried pineapple cubes at sugar concentration as 40, 50 and 60^{0}B and soaking temperature 30, 45 and 60^{0}C were exposed at 40, 50 and 60^{0}C in the convective hot air dryer. Fig. 6(a) shows the moisture content (%db) w.r.t. time (minutes) of osmotically dried cubes dried at 30^{0}C soaking temperature at 40^{0}B sugar concentration and exposed to 40^{0}C, 50^{0}C and 60^{0}C hot air temperature. It took around 1320, 1080 and 720 minitues to dry the product from an initial moisture content 399.75 (%db) to 4.16 (%db). Fig. 6(B) shows the moisture content (%db) w.r.t. time (minutes) of osmotically dried pineapple cubes dried at 45^{0}C soaking temperature at 40^{0}B sugar concentration and exposed to 40^{0}C, 50^{0}C and 60^{0}C hot air temperature. It took around 1200, 960 and 660 minutes to dry the product from an initial moisture content 316.49 (%db) to 5.63 (%db). Fig. 6(c) shows the moisture content (%db) w.r.t. time (minutes) of osmotically dried pineapple cubes dried at 60^{0}C soaking temperature and at 40^{0}B sugar concentration and exposed to 40^{0}C, 50^{0}C and 60^{0}C hot air temperature. It took around 1080, 840 and 540 minutes to dry the product from an initial moisture content 316.49 (% db) to 5.62 (% db). Similar trends (trends not shown) were observed in moisture content (% db) versus (time) of osmotically dried pineapple cubes dried at soaking temperature at 30,

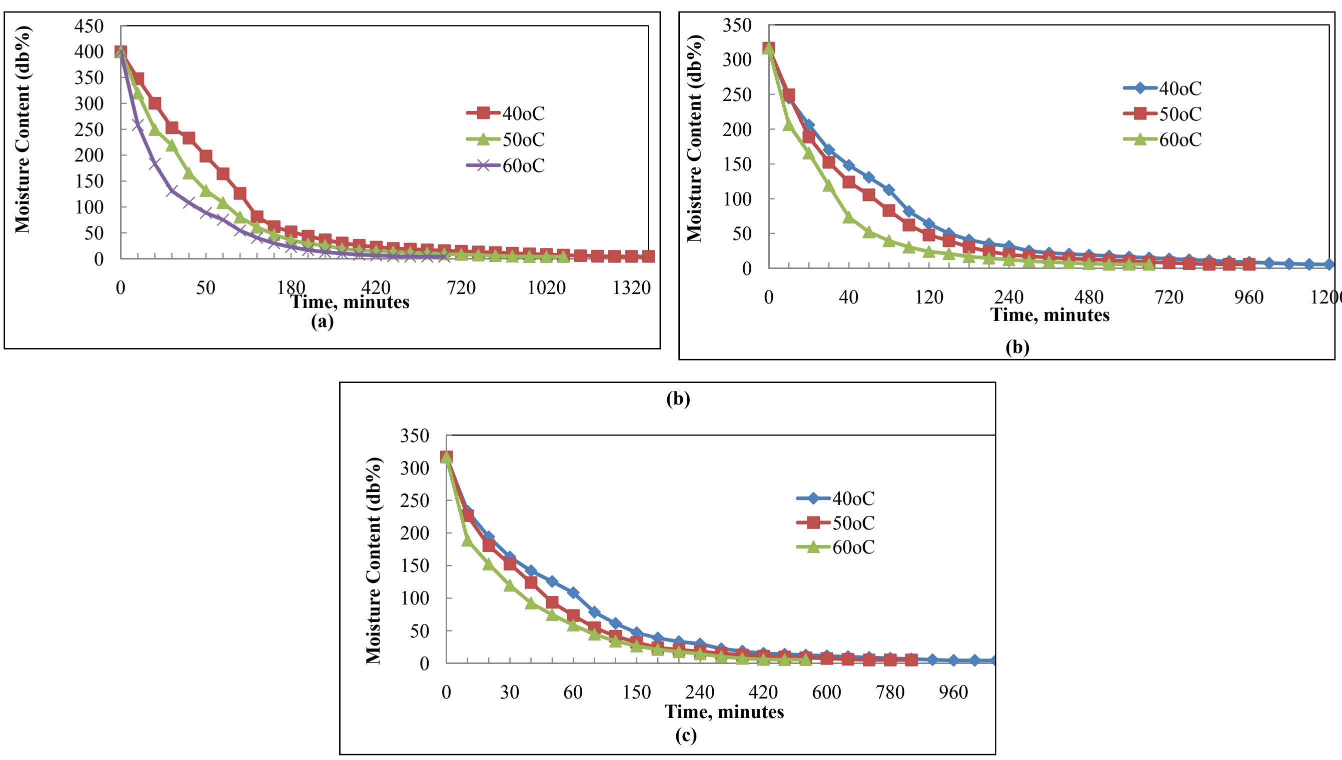

Fig. 6: Moisture content (%db) versus time (min) at soaking temperature of pineapple cubes at (a)30^{o}C, (b)45^{o}C and (c)60^{o}C in sugar concentration (40^{o}B) at Drying temperatures (40, 50 and 60^{o}C)

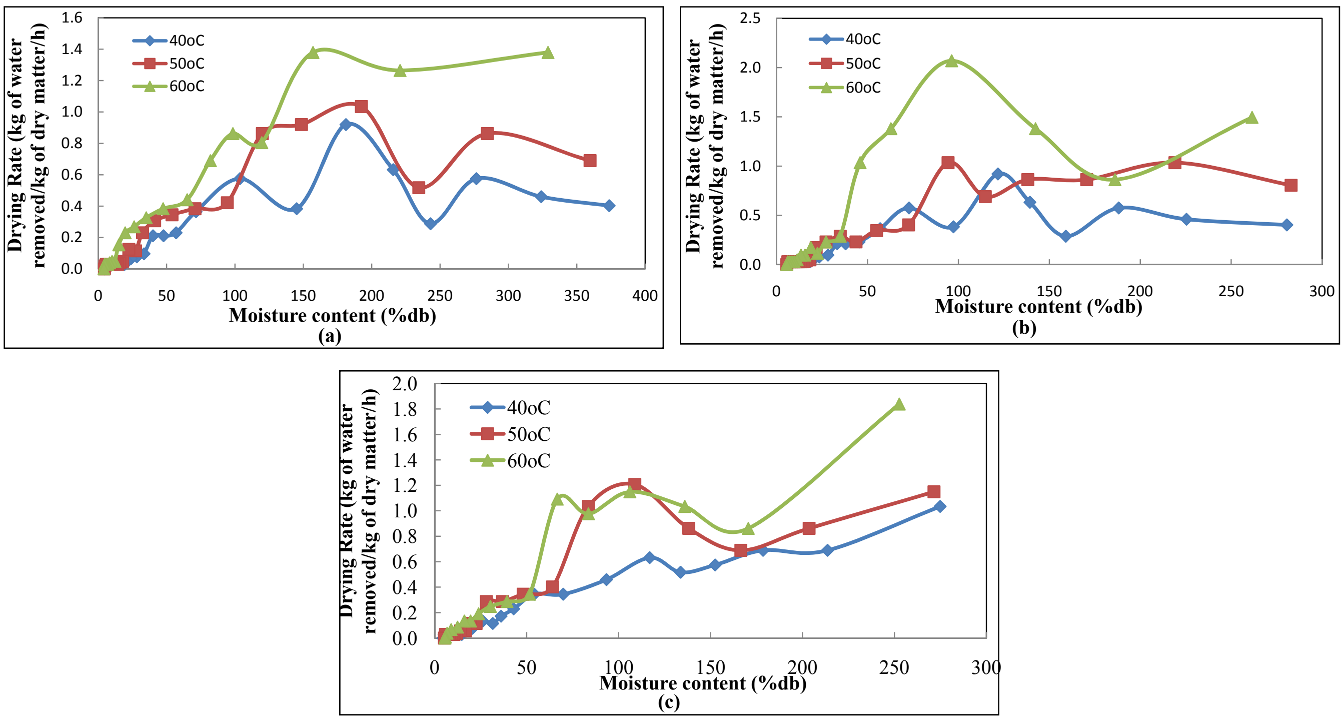

Fig. 7: Drying Rate (kg of water removed/kg of dry matter/h) versus Moisture content (%db) at soaking temperature of pineapple cubes at (a)30°C; (b)45°C; and (c)60°C in Sugar concentration (40°B) at Drying temperatures (40, 50 and 60°C)

45 and 60⁰C in sugar concentration 50⁰B and 60⁰B at drying temperature 40⁰C, 50⁰C and 60⁰C respectively. The drying take place in a falling rate period Table 6 shows the initial and final moisture content (%db) of osmotically dried pineapple cubes dried by convective hot air drying at 40⁰B, 50⁰B and 60⁰B sugar concentration soaked at 30, 45 and 60⁰C and dried at 40, 50 and 60⁰C.

Fig. 7 shows the drying rate (kg of water removed/kg of dry matter/h) w.r.t. moisture content (%db) of osmo-convective dried pineapple cubes, at sugar concentration (40⁰B) and at soaking temperature (a) 30⁰C; (b) 45⁰C; and (c) 60⁰C and convectively dried at 40, 50 and 60⁰C respectively. The drying took place in the falling rate period. The drying rate decreases with the decreases in the moisture content and it reaches to zero at the final moisture content of the osmo-convective dried of pineapple cubes. The drying rate increases 0.402, 0.689 and 1.379 kg of water removed/kg of dry matter/h as the convective hot air temperature increases from 40⁰C to 60⁰C at 40⁰B sugar concentration and soaked at 30⁰C. The drying rate increases 0.402- 1.494 kg of water removed/kg of dry matter/h as the convective hot air temperature increases from 40⁰C to 60⁰C at 40⁰B sugar concentration and soaking temperature at 45⁰C. Similarly, the drying rate increases from 1.034-1-839 kg of water removed/kg of dry matter/h as the convective hot air temperature increases from 40⁰C to 60⁰C at 40⁰B sugar concentration and soaked at 60⁰C. Table 6 shows the effect of sugar concentration (40⁰B, 50⁰B and 60⁰B), soaking temperature (30, 45 and 60⁰C) and convective hot air drying temperature (40⁰C, 50⁰C and 60⁰C) on the drying rate of pineapple cubes dried by osmo-convective drying. From the Table 5.6, it revealed that at 50⁰B sugar concentration and soaking temperature 30⁰C, as the temperature of the convective hot air dryer increases from 40⁰C-60⁰C, the drying rate increases from 0.689-1.896 kg of water removed/kg of dry matter/h. similarly at 45⁰C and 60⁰C soaking temperature as the temperature of convective hot air dryer increases from 40⁰C-60⁰C, the

Table 6: Initial and final moisture content (%db), drying rate data for osmotically dried pineapple cubes dried at convective hot air drying methods

Sl. No.	Sugar Concentration (^{0}B)	Soaking temperature (^{o}C)	Convective hot air drying temperature (^{o}C)	Initial MC (% db)	Final MC (% db)	Drying rate minutes	Drying Rate (kg of water removed/kg of dry matter/h) ceases from to
1	40	30	40	399.75	4.16	1320	0.402-0.0
			50	399.75	4.16	1080	0.689-0.0
			60	399.75	4.16	720	1.379-0.0
		45	40	316.49	5.63	1200	0.402-0.0
			50	316.49	5.63	960	0.804-0.0
			60	316.49	5.63	660	1.494-0.0
		60	40	316.49	5.62	1080	1.034-0.0
			50	316.49	5.62	840	1.149-0.0
			60	316.49	5.62	540	1.839-0.0
2	50	30	40	254.23	4.64	1200	0.689-0.0
			50	254.23	4.64	960	1.091-0.0
			60	254.23	4.64	600	1.896-0.0
		45	40	225.94	4.52	960	1.206-0.0
			50	225.94	4.52	780	1.609-0.0
			60	225.94	4.52	540	2.241-0.0
		60	40	158.53	4.52	840	1.206-0.0
			50	158.53	4.52	720	1.379-0.0
			60	158.53	4.52	540	1.896-0.0
3	60	30	40	225.94	3.79	1020	0.689-0.0
			50	225.94	3.79	900	0.517-0.0
			60	225.94	3.79	480	1.264-0.0
		45	40	163.08	4.52	900	1.379-0.0
			50	163.08	4.52	780	1.551-0.0
			60	163.08	4.52	420	1.954-0.0
		60	40	120.55	4.89	720	1.494-0.0
			50	120.55	4.89	600	1.724-0.0
			60	120.55	4.89	360	2.241-0.0

Significant at p≤0.01.

drying rate increases from 1.206-2.241 and 1.206-1.896 kg of water removed/kg of dry matter/h respectively. At sugar concentration 60^{0}B and soaking temperature 30^{0}C, 45^{0}C and 60^{0}C at convective hot air drying of pineapple cubes, the drying rate was in the range of 0.689-1.264, 1.379-1.954 and 1.494-2.241 kg of water removed/kg of dry matter/h respectively.

Table 7 shows the effect of sugar concentration (^{0}B), soaking temperature (^{0}C) and convective hot air drying temperature on constants of Hendersons and Pabis Model. '*a*' represents the coefficient of thin layer model and '*k*' represents the drying constant (min/h). It was observed from Table 7 that the Hendersons and Pabis Model was well fitted to the experimental data $r^2 \geq 0.753$. The coefficient of thin layer model '*a*' was in the range of 0.481 to 0.839 and drying costant was 0.004197-0.015772 (min/h) for sugar concentration 400B. The trend shows that the drying constant increases from 0.004197 to 0.01288, 0.005104 to 0.0139935 and 0.00779 to 0.001577(min/hr) with

Table 7: Effect of sugar concentration (^{0}B), soaking temperature (^{0}C) and Convective hot air drying temperature on drying of component of Hendersons and Pabis Model

Sl. No.	Sugar Concentration (^{0}B)	Soaking temperature (^{o}C)	Convective hot air drying temperature (^{o}C)	a	K (min/hr)	r^2
1	40	30	40	0.4812	0.004197	0.924
			50	0.7273	0.008082	0.776
			60	0.6865	0.012889	0.879
		45	40	0.5563	0.005104	0.788
			50	0.6774	0.008374	0.815
			60	0.6285	0.013993	0.868
		60	40	0.8395	0.007797	0.754
			50	0.6756	0.009764	0.863
			60	0.8393	0.015772	0.889
2	50	30	40	0.8875	0.005962	0.817
			50	0.8803	0.008085	0.848
			60	0.9214	0.013459	0.886
		45	40	1.0514	0.008548	0.779
			50	0.8980	0.010808	0.818
			60	0.9741	0.018988	0.865
		60	40	0.8081	0.007641	0.753
			50	1.0954	0.012391	0.820
			60	1.1905	0.018760	0.871
3	60	30	40	1.4175	0.008220	0.792
			50	1.1249	0.009609	0.809
			60	0.9632	0.018585	0.912
		45	40	0.8021	0.008234	0.801
			50	0.6879	0.009913	0.816
			60	1.3615	0.027988	0.880
		60	40	0.9193	0.011104	0.806
			50	0.8669	0.014308	0.851
			60	1.1225	0.028458	0.891

Significant at $p \leq 0.01$.

increases in temperature of convective hot air 40^{0}C to 60^{0}C for 30^{0}C, 45^{0}C and 60^{0}C soaking temperature.

As the soaking temperature increases from 30^{0}C to 60^{0}C the drying constant also increases. At 50^{0}B sugar concentration, as the temperature of convective hot air drying increases from 40^{0}C to 60^{0}C the drying constant were 0.005962 to 0.013459, 0.0085481 to 0.01898 and 0.0076414 to 0.018760(min/hr). The drying constant increases with increases in temperature; also it increases with increases in soaking temperature of pineapple cubes. Similarly at 60^{0}B sugar concentration, as the temperature of convective hot air drying increases from 40^{0}C to 60^{0}C the drying constant were 0.00822058-0.01858566, 0.00823496-0.02798883 and 0.011104647-0.02845828 (min/h) respectively. The drying constant found to be increased with increase in convective hot air temperature; also it increases with increased in soaking temperature of pineapple cubes.

1. Effective diffusivity and activation energy of osmotically dried pineapple cubes drying by convective hot air drying

Fig. 8 and 9 shows graph of Ln (MR) versus time, min for osmotically dried pineapple cubes at varied sugar concentration 40, 50 and 60^{0}B, soaking temperature 30, 45 and 60^{0}C and at convective hot air drying temperature at 40, 50 and 60 ^{0}C respectively. Linear equations obtained from the graph were compared with the standard equation i.e. $y = mx + c$. "m" value indicates the slope of line.

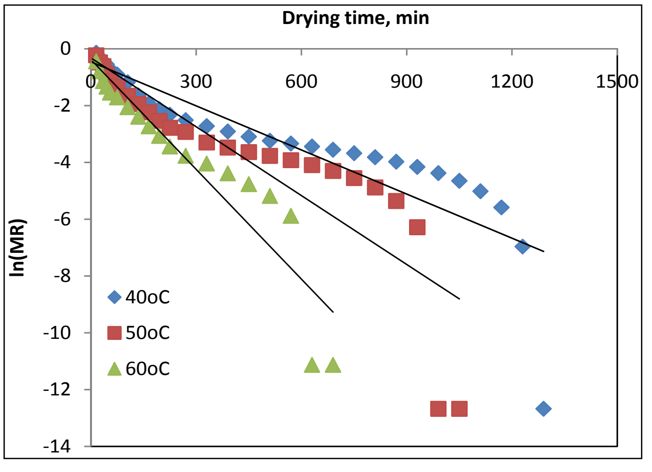

Fig. 8: Ln (MR) versus time, min for effective diffusivity of dried pineapple cubes at sugar concentration 40^{0}B, soaking temperature 30^{0}C and drying temperature 40, 50 and 60^{0}C

Effective diffusivity (D_{eff}) at time (t) for osmotically dried pineapple cubes were at sugar concentration 40^{0}B, soaking temperature 30^{0}C and temperature at 40, 50 and 60 ^{0}C respectively 6.30197×10^{-8}, 9.83676 × 10^{-8} and 1.56881 ×10^{-7} m^2/s, As the sugar concentration 40^{0}B, soaking temperature 45^{0}C and drying temperature at 40, 50 and 60 ^{0}C respectively the value of diffusivity were 6.21203 ×10^{-8}, 1.01911 ×10^{-7} and 1.3874 ×10^{-7} m^2/s and for sugar concentration 40^{0}B, soaking temperature 60^{0}C and drying temperature at 40, 50 and 60 ^{0}C respectively 9.49046 ×10^{-8}, 1.18844 ×10^{-7} and 1.91968 ×10^{-7} m^2/s. Similar type of trends were observed at 50^{0}B, and 60^{0}B sugar concentration (trends no shown) shown Table 8 the diffusivity values of sugar concentration 50 and 60^{0}B, soaking temperature 30, 45 and 60^{0}C and temperature at 40, 50 and 60 ^{0}C respectively calculated from equation (3.11) by convective hot air drying method at 40, 50 and 60 ^{0}C (shown in Table 8).

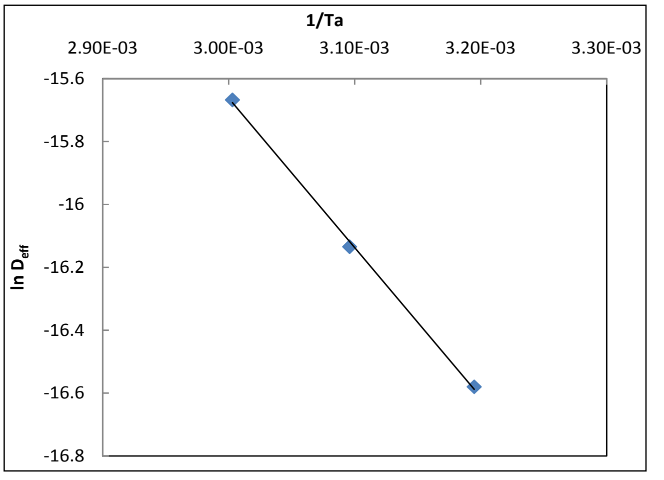

Fig. 9: Arrhenius- type relationship between effective diffusivity and temperature for osmotically dried pineapple cubes at sugar concentration 40^{0}B, soaking temperature 30^{0}C and drying temperature 40, 50 and 60^{0}C

The values of effective diffusivity (D_{eff}) were in the range of 6.30197×10^{-8} and 1.00052×10^{-7} m^2/s over the temperature range 40- 60 ^{0}C for (Wilton *et al.* 2014), 0.78×10^{-10} to 3.46 ×10^{-10} m^2/s for apple at drying temperature 30 - 50^{0}C and sugar concentration 50 to 70^{0}B, 1.48×10^{-10} to 3.24×10^{-10} m^2/s for pineapple piece at drying temperature 30 -50^{0}C and sugar concentration 40 to 70^{0}B (Rastogi and Raghavarao., 2004) and 1.01×10^{-10} to 4.22×10^{-10} m^2/s for pineapple piece at drying temperature 50-80^{0}C and sugar concentration 40 to 60^{0}B (Uddin and Hawaladar., 1990). Diffusivities obtained for other food materials, as reported in literature are quite similar in order of magnitude as compared to the present values, 3.6×10^{-10} m^2/s for apple at 76°C (Roman *et al.* 1979), 3.3 ×10^{-10} m^2/s for avocado at 56°C (Alzamora *et al.* 1980). Diffusivity of pineapple slices 9.26×10^{-10}, 7.21×10^{-10} and 1.50×10^{-10} at varied drying temperature 55, 65 and 75^{0}C (Singh *et al.* 2014), The average effective moisture diffusivity for moisture during convective dehydration of pears was found to be 2.06 – 6.37 × 10^{-10} m^2/s for un-osmosed pears and 1.87–8.12×10^{-10}m^2/s for pre-osmosed pears in sucrose syrup Park *et al.* (2002). Karathanos, Kostaropoulus, and Saravacos

Table 8: Osmo-convective drying of pineapple cubes activation energy

Sugar Conc. (°B)	Soaking Temp. (°C)	Convective drying temp. (°C)	Diffusivity (m²/s)	D_0 (m²/s)	Activation energy (E_a (kJ/mol))
40	30	40	6.30197×10^{-8}	5.5350×10^{5}	246.18
		50	9.83676×10^{-8}		
		60	1.56881×10^{-7}		
	45	40	6.21203×10^{-8}	2.9965×10^{5}	223.30
		50	1.01911×10^{-7}		
		60	1.38743×10^{-7}		
	60	40	9.49046×10^{-8}	3.6520×10^{5}	220.39
		50	1.18844×10^{-7}		
		60	1.91968×10^{-7}		
50	30	40	7.25679×10^{-8}	4.5909×10^{5}	237.04
		50	9.84104×10^{-8}		
		60	1.63824×10^{-7}		
	45	40	1.04039×10^{-7}	6.5647×10^{5}	238.36
		50	1.31547×10^{-7}		
		60	2.31102×10^{-7}		
	60	40	9.30026×10^{-8}	8.2394×10^{5}	247.81
		50	1.36794×10^{-7}		
		60	2.28333×10^{-7}		
60	30	40	1.00052×10^{-7}	7.5389×10^{5}	246.27
		50	1.16954×10^{-7}		
		60	2.26204×10^{-7}		
	45	40	1.00227×10^{-7}	18.3142×10^{5}	272.18
		50	1.20653×10^{-7}		
		60	3.40649×10^{-7}		
	60	40	1.34585×10^{-7}	23.1515×10^{5}	278.84
		50	1.38155×10^{-7}		
		60	3.46359×10^{-7}		

(1995) also found that D_e was 16 $\times10^{-10}$m²/s in apples air-dried at 55⁰C, while this parameter decreased to 5×10^{-10} m²/s, when samples were osmotically pre-treated in 45⁰B sucrose solution. D_{eff} = 1.93 $\times10^{-10}$ m²/s at 60°C and activation energy E_a = 24.6 kJ/mol. Gekas and Lamberg (1991) measured 2.3 x10^{-10} m²/s at 60°C for D_{eff} in potato.

Fig. 9 shows the linear relationship between ($ln\ D_{eff}$) and ($1/T_a$) as plotted for pineapple cubes. The diffusivity constant or pre- exponential factor of Arrhenius equation (D_0) and activation of energy (E_a) calculated from the linear regression (shown in Table 8) at varied sugar concentration 40, 50 and 60⁰B, soaking temperature 30, 45 and 60⁰C and temperature at 40, 50 and 60 ⁰C respectively for osmotically dried pineapple cubes dried by convective hot air drying were at sugar concentration 40⁰B, soaking temperature 30⁰C and temperature at 40, 50 and 60 ⁰C respectively the diffusivity constant 5.5350×10^{5} m²/s and activation energy 246.18 kJ/mol, At sugar concentration 40⁰B, soaking temperature 45⁰C and temperature at 40, 50 and 60 ⁰C respectively the diffusivity constant was 2.9965×10^{5} m²/s and activation energy was 223.30 kJ/mol. At the sugar concentration 40⁰B, soaking temperature 60⁰C and temperature at 40, 50 and 60 ⁰C respectively, the diffusivity constant 3.6520×10^5 m^2/s and activation energy was 220.39 kJ/mol respectively. At 50^0B sugar concentration at 30, 45 and 60^0C soaking temperature the diffusivity coefficients were 4.5909×10^5, 6.5647×10^5 and 8.2394×10^5 m^2/s and the activation energy were 237.04, 238.30 and 247.81 kJ/mole respectively. Similarly at 60^0B sugar concentration at 30, 45 and 60^0C soaking temperature the diffusivity coefficients were 7.53×10^5, 18.31×10^5 and 23.15×10^5 m^2/s and the activation energy were 246.77, 272.18 and 278.84 kJ/mole respectively. For sugar concentration 50 and 60^0B, soaking temperature 30, 45 and 60^0C and temperature at 40, 50 and 60 ^{0}C respectively calculated from equation (10) by convective hot air drying method at 40, 50 and 60 ^{0}C. Bahadur Singh**,** 2006 reported that the activation energy for the convective drying of carrot cubes is 22.1426 kJ/mole for un-osmosed samples, which was 10.00, 14.87, 16.21 kJ/mole in case of NaCl salt, sucrose, and mixture of sucrose–NaCl salt, respectively.

Osmo-Convective drying quality characteristics

Quality characteristics of pineapple cubes include TSS, pH, acidity, reducing sugar, non-reducing sugar, Total sugar. Pineapple cubes dried at varied sugar concentration 40, 50 and 60^0B, soaking temperature of 30, 45 and 60^0C and drying temperature of 40, 50 and 60^0C respectively.

1. TSS

Table 9 shows the effect of drying temperature, sugar concentration and soaking temperature on the TSS (%) of the dried pineapple cubes. The TSS for pineapple cubes were in the range of 19.62-32.42% for all the drying temperature (40, 50 and 60^0C), at varied sugar concentration (40 to 60°Brix) and soaking temperature (30 to 60^0C). TSS for drying temperature 40^0C ranges from 19.62-27.49%, for drying temperature 50^0C from 21.86-29.29% and for drying temperature 60^0C from 24.43-32.42% respectively for all the sugar concentration (40 to 60°Brix) and soaking temperature (30 to 60^0C). Table 9 shows it was minimum 19.62% at 40^0Brix sugar concentration, 30^0C soaking temperature and 40^0C drying temperature and was maximum 32.42% at 60^0Brix sugar concentration, 60^0C soaking temperature and 60^0C drying temperature. TSS content in pineapple cubes increases as sugar concentration and soaking temperature, and drying temperature increases.

As the sugar concentration increases from 40°B to 60°B, the TSS of the dried pineapple cubes increases for all drying temperature. However in drying temperature 400C the TSS increases gradually form sugar concentration 40°C to 60°Brix. Similarly in drying temperature 600C TSS increases rapidly from sugar concentration 40 to 60°Brix. Similarly as the soaking temperature of the pineapple cubes increases from 30 to 60^0C TSS increases for all drying temperature. During drying of pineapple cubes drying temperature play important role in TSS of the dried pineapple cubes.

Table 9 shows the ANOVA for the effect of drying temperature, sugar concentration, soaking temperature on the TSS of the pineapple cubes. It is clear from the table that TSS is significantly affected ($p\leq0.05$) by the drying temperature, sugar concentration, soaking temperature. The interaction between the drying temperature, sugar concentration, soaking temperature has a significant influence on the TSS. The interactions among independent variables significantly affected the TSS values of pineapple cubes ($p \leq 0.05$).

Increase in sugar concentration resulted in increase in TSS. similar observations were reported by Rai *et al.* (2007) that there was increase in total soluble solids of osmotic dehydrated pineapple slices when slices were treated with maximum sugar solution concentration having final TSS increased. TSS content osmotically dried pineapple cubes at 50^0B sugar concentration 24.27% (Expedito *et al.* 1996).

2. pH

Table 10 shows the effect of drying temperature, sugar concentration and soaking temperature on the pH of the dried pineapple cubes. The pH for pineapple cubes were in the range of 3.90-4.74 for all the drying temperature (40, 50 and 60^0C), at varied

Table 9: Effect of sugar concentration, soaking temperature and temperature of osmo-convective drying on TSS of dried pineapple cubes

Drying Temp	Sugar concentration 40°Brix			Sugar concentration 50°Brix			Sugar concentration 60°Brix		
	Soaking Temp 30°C	**Soaking Temp 45°C**	**Soaking Temp 60°C**	**Soaking Temp 30°C**	**Soaking Temp 45°C**	**Soaking Temp 60°C**	**Soaking Temp 30°C**	**Soaking Temp 45°C**	**Soaking Temp 60°C**
40°C	19.62^{o}	22.18^{m}	23.60^{l}	23.35^{l}	24.73^{i}	25.61^{h}	23.46^{l}	27.36^{f}	27.49^{ef}
50°C	21.86^{n}	22.36^{m}	25.39^{h}	23.90^{k}	26.84^{g}	27.49^{ef}	27.81^{d}	28.78^{c}	29.29^{b}
60°C	24.43^{j}	24.95^{i}	27.49^{ef}	25.60^{h}	27.71^{ed}	28.61^{c}	28.69^{c}	29.36^{b}	32.42^{a}

ANOVA

		Source of Variation	**Df**	**SS**	**MS**	**F**	**P-value**	**F critical**
SE_1	0.032552	Sugar Concentration	2	304.850	152.428	5326.48	<.0001	2.007
CD_1 at 0.05%	0.0924	Soaking Temperature	2	137.190	68.597	2397.06	<.0001	2.007
SE_2	0.056382	Drying Temperature	2	169.246	84.623	2957.09	<.0001	2.007
CD_2 at 0.05%	0.160002	Sugar Concentration and Soaking Temperature	4	5.679	1.420	49.61	<.0001	2.007
SE_3	0.097656	Sugar Concentration and Drying Temperature	4	7.541	1.885	65.88	<.0001	2.007
CD_3 at 0.05	0.277131	Soaking Temperature and Drying Temperature	4	7.020	1.755	61.33	<.0001	2.007
		Sugar concentration Soaking Temperature and Drying Temperature	8	15.084	1.885	65.89	<.0001	2.007
	Replication	2	0.004	0.002	0.06	0.9405		
	Error	52	1.488	0.029				
	Corrected Total	80	648.112					

Same letter are not significantly different, SE_1= Effect of individual Sugar concentration or soaking temperature or drying temperature on TSS, SE_2= Effect of sugar concentration and soaking temperature, effect of sugar concentration and drying temperature, effect of soaking temperature and drying temperature on TSS, SE_3= Combine effect sugar concentration, soaking temperature and drying temperature on TSS.

Table 10: Effect of sugar concentration, soaking temperature and temperature of osmo-convective drying on pH of dried pineapple cubes

Drying Temp	Sugar concentration 40°Brix			Sugar concentration 50°Brix			Sugar concentration 60°Brix		
	Soaking Temp 30°C	Soaking Temp 45°C	Soaking Temp 60°C	Soaking Temp 30°C	Soaking Temp 45°C	Soaking Temp 60°C	Soaking Temp 30°C	Soaking Temp 45°C	Soaking Temp 60°C
40°C	3.90^{m}	3.91^{k}	3.86m	3.95^{kj}	3.96^{k}	4.04h	4.02^{ih}	3.97^{ij}	4.16^{g}
50°C	4.03^{h}	4.04^{h}	4.15^{g}	4.38^{cd}	4.26^{f}	4.25^{f}	4.54^{b}	4.14^{g}	4.33^{e}
60°C	4.32^{e}	4.52^{b}	4.33^{e}	4.44^{j}	4.55^{b}	4.45^{c}	4.74^{a}	4.35^{ed}	4.52^{b}

ANOVA

		Source of Variation	Df	SS	MS	F	P-value	F critical
SE_1	0.006179	Sugar Concentration	2	0.5115432	0.256	248.05	<.0001	2.007
CD_1 at 0.05%	0.01750	Soaking Temperature	2	0.0666247	0.033	32.31	<.0001	2.007
SE_2	0.010703	Drying Temperature	2	3.3089284	1.654	1604.49	<.0001	2.007
CD_2 at 0.05%	0.030373	Sugar Concentration and Soaking Temperature	4	0.319	0.080	77.33	<.0001	2.007
SE_3	0.018538	Sugar Concentration and Drying Temperature	4	0.057	0.014	13.94	<.0001	2.007
CD_3 at 0.05	0.052608	Soaking Temperature and Drying Temperature	4	0.120	0.030	29.12	<.0001	2.007
		Sugar concentration Soaking Temperature and Drying Temperature	8	0.201	0.025	24.34	<.0001	2.007
	Replication	2	0.006	0.003	2.84	0.0678		
	Error	52	0.054	0.001				
	Corrected Total	80	4.644					

Same letter are not significantly different, SE_1= Effect of individual Sugar concentration or soaking temperature or drying temperature on pH, SE_2= Effect of sugar concentration and soaking temperature, effect of sugar concentration and drying temperature, effect of soaking temperature and drying temperature on pH, SE_3= Combine effect sugar concentration, soaking temperature and drying temperature on pH.

sugar concentration (40 to 60°Brix) and soaking temperature (30 to 60^{0}C). pH for drying temperature 40^{0}C ranges from 3.90-4.16, for drying temperature 50^{0}C from 4.03-4.54 and for drying temperature 60^{0}C from 4.32-4.74 respectively for all the drying temperature (40 to 60^{0}C), sugar concentration (40 to 60°Brix) and soaking temperature (30 to 60^{0}C). Table 10 shows it was minimum 3.90 at 40^{0}Brix sugar concentration, 30^{0}C soaking temperature and 40^{0}C drying temperature and was maximum 4.52 at 60^{0}Brix sugar concentration, 60^{0}C soaking temperature and 60^{0}C drying temperature. pH of pineapple cubes increases as sugar concentration and drying temperature increases. Also acidity of pineapple cubes decreases then pH of pineapple cubes increases vice versa.

As the sugar concentration increases from 40°B to 60°Brix, the pH of the dried pineapple cubes increases for all drying temperatures. However in drying temperature 40^{0}C the pH increases gradually form sugar concentration 40°B to 60°Brix. Similarly in drying temperature 60^{0}C, pH increases rapidly from sugar concentration 40 to 60°Brix. Similarly as the soaking temperature of the pineapple cubes increases from 30 to 60^{0}C, pH increases for all drying temperatures. During drying of pineapple cubes drying temperature play important role on pH of the dried pineapple cubes.

Table 10 shows the ANOVA for the effect of drying temperature, sugar concentration, soaking temperature on the pH of the pineapple cubes. It is clear from the Table 10 that pH is significantly affected ($p \le 0.05$) by the drying temperature, sugar concentration, soaking temperature. The interaction between the drying temperature, sugar concentration, soaking temperature has a significant difference on the pH. The interactions among independent variables significantly affected the pH values of pineapple cubes ($p \le 0.05$).

Increase in sugar concentration resulted in increase in pH. similar observations were reported by Exepedito *et al*. (1996) that there was increase in pH of osmotic dehydrated pineapple slices when slices were treated with 70^{0}B sugar solution having final pH as 3.52. The pH of the dehydrated pineapple increased from 4.95 to 5.61 for sugar concentration 40^{0}B and soaking temperature 60^{0}C. Perio-Mena *et al.* 2006 reported that pH increased 3-1 to 3.4 at 50^{0}B sugar concentration.

3. Acidity

Table 11 shows the effect of drying temperature, sugar concentration and soaking temperature on the acidity (%) of the dried pineapple cubes. The acidity for pineapple cubes were in the range of 0.651-0.983% for all the drying temperature (40, 50 and 60^{0}C), at varied sugar concentration (40 to 60°Brix) and soaking temperature (30 to 60^{0}C). Acidity for drying temperature 40^{0}C ranges from 0.776-0.983%, for drying temperature 50^{0}C from 0.748-0.981% and for drying temperature 60^{0}C from 0.612-0.651% respectively for all the drying temperature (40 to 60^{0}C), sugar concentration (40 to 60°Brix) and soaking temperature (30 to 60^{0}C Table 11 shows it was maximum 0.983% at 40^{0}Brix sugar concentration, 30^{0}C soaking temperature and 40^{0}C drying temperature and was minimum 0.612% at 60^{0}Brix sugar concentration, 60^{0}C soaking temperature and 60^{0}C drying temperature. Acidity in pineapple cubes decreases as sugar concentration and drying temperature increases. Also pH of pineapple cubes increases then acidity of pineapple cubes decreases vice versa.

As the sugar concentration increases from 40°B to 60°Brix, the acidity of the dried pineapple cubes decreases for all drying temperature. Similarly as the soaking temperature of the pineapple cubes increases from 30 to 60^{0}C acidity decreases for all drying temperatures. Temperature play important role during drying of pineapple cubes drying on acidity of the dried pineapple cubes.

Table 11 and shows the ANOVA for the effect of drying temperature, sugar concentration, soaking temperature on the acidity of the dried pineapple cubes. It is clear from the Table that acidity is significantly affected ($p \le 0.05$) by the drying temperature, sugar concentration, soaking temperature. The interaction between the drying temperature, sugar concentration,

Table 11: Effect of sugar concentration, soaking temperature and temperature of osmo-convective drying on acidity of dried pineapple cubes

Drying Temp	Sugar concentration 40°Brix			Sugar concentration 50°Brix			Sugar concentration 60°Brix		
	Soaking Temp 30°C	Soaking Temp 45°C	Soaking Temp 60°C	Soaking Temp 30°C	Soaking Temp 45°C	Soaking Temp 60°C	Soaking Temp 30°C	Soaking Temp 45°C	Soaking Temp 60°C
40°C	0.983[a]	0.919[b]	0.936[b]	0.943[b]	0.921[b]	0.803[dc]	0.804[dc]	0.930[b]	0.776[de]
50°C	0.981[a]	0.804[dc]	0.799[dc]	0.734[f]	0.810[c]	0.729[f]	0.695[hg]	0.799[dc]	0.748[fe]
60°C	0.612[j]	0.674[hi]	0.725[fg]	0.613[j]	0.674[hi]	0.674[hi]	0.554[k]	0.735[f]	0.651[i]

ANOVA

		Source of Variation	Df	SS	MS	F	P-value	F critical
SE_1	0.003796	Sugar Concentration	2	0.097	0.048	124.67	<.0001	2.007
CD_1 at 0.05%	0.0108	Soaking Temperature	2	0.034	0.017	43.81	<.0001	2.007
SE_2	0.006574	Drying Temperature	2	0.741	0.371	953.44	<.0001	2.007
CD_2 at 0.05%	0.018657	Sugar Concentration and Soaking Temperature	4	0.092	0.023	59.13	<.0001	2.007
SE_3	0.011387	Sugar Concentration and Drying Temperature	4	0.031	0.008	19.88	<.0001	2.007
CD_3 at 0.05	0.032315	Soaking Temperature and Drying Temperature	4	0.071	0.018	45.6	<.0001	2.007
		Sugar concentration Soaking Temperature and Drying Temperature	8	0.053	0.007	16.97	<.0001	2.007
	Replication	2	0.002	0.001	2.92	0.063		
	Error	52	0.020	0.000				
	Corrected Total	80	1.142					

Same letter are not significantly different, SE_1= Effect of individual Sugar concentration or soaking temperature or drying temperature on acidity, SE_2= Effect of sugar concentration and soaking temperature, effect of sugar concentration and drying temperature, effect of soaking temperature and drying temperature on acidity, SE_3= Combine effect sugar concentration, soaking temperature and drying temperature on acidity.

soaking temperature has a significant difference in the acidity. The interactions among independent variables significantly affected the acidity values of pineapple cubes ($p \leq 0.05$).

Increase in sugar concentration resulted in decrease in acidity. Similar observations were reported by Heng *et al*. (1990) reported that in cases of papaya, temperatures above 60°C should be avoided because they lead to significant ascorbic acid out flow and dis-colouration. Santos *et al*. 2014 studied that acidity in pineapple 0.426 at 40^{0}C drying temperature. Expedito *et al.* 1996 studied that acidity of osmotically dried pineapple 0.49% at 70^{0}B sugar concentration and drying at 50^{0}C.

4. Reducing sugar

Table 12 shows the effect of drying temperature, sugar concentration and soaking temperature on the reducing sugar (%) of the dried pineapple cubes. The reducing sugar for pineapple cubes were in the range of 12.29-19.08% for all the drying temperature (40, 50 and 60^{0}C), at varied sugar concentration (40 to 60°Brix) and soaking temperature (30 to 60^{0}C). A Reducing sugar of dehydrated pineapple cubes at for drying temperature 40^{0}C ranges from 12.29-17.64%, for drying temperature 50^{0}C from 13.78-18.20% and for drying temperature 60^{0}C from 14.82-19.08% respectively for all the drying temperature (40 to 60^{0}C), sugar concentration (40 to 60°Brix) and soaking temperature (30 to 60^{0}C). Table 12 also indicated that reducing sugar was minimum 12.29% at 40^{0}Brix sugar concentration, 30^{0}C soaking temperature and 40^{0}C drying temperature and was maximum 19.08% at 60^{0}Brix sugar concentration, 60^{0}C soaking temperature and 60^{0}C drying temperature. Reducing sugar content in dried pineapple cubes is increased for increases in soaking temperature and drying temperature.

As the sugar concentration increases from 40°B to 60°Brix, the reducing sugar of the dried pineapple cubes increases for all drying temperature. However at the drying temperature 40^{0}C the reducing sugar increases gradually from sugar concentration 40°B to 60°Brix. Similarly in drying temperature 60^{0}C reducing sugar increases rapidly from sugar concentration 40 to 60°Brix. Similarly as the soaking temperature of the pineapple cubes increases from 30 to 60^{0}C reducing sugar increases for all drying temperature. During drying of pineapple cubes drying temperature play a significant role in reducing sugar of the dried pineapple cubes.

Table 12 shows the ANOVA for the effect of drying temperature, sugar concentration, soaking temperature on the reducing sugar of the pineapple cubes. It is clear from the table that reducing sugar is significantly affected ($p \leq 0.05$) by the drying temperature, sugar concentration, soaking temperature. The interaction between the drying temperature, sugar concentration, soaking temperature has also a significant effect ($p \leq 0.05$) on the reducing sugar. The interactions among independent variables significantly affected the reducing sugar values of pineapple cubes ($p \leq 0.05$).

Increase in sugar concentration resulted in increase in reducing sugar reported by Hope *et al.* (1972) for banana and ripe mango. Sagar *et al.* (1999) estimated that the reducing sugar percentage of dehydrated mango slices was in the range of 25.35 to 29.79 per cent. Expedito *et al.* 1996 repored that reducing sugar of osmotically dried pineapple 35.48% at 70^{0}B sugar concentration and drying at 50^{0}C.

5. Non-Reducing sugar

Table 13 shows the effect of drying temperature, sugar concentration and soaking temperature on the non-reducing sugar (%) of the dried pineapple cubes. The non-reducing sugar for pineapple cubes were in the range of 31.98-41.78% for all the drying temperature (40, 50 and 60^{0}C), at varied sugar concentration (40 to 60°Brix) and soaking temperature (30 to 60^{0}C). A non-reducing sugar for drying temperature 40^{0}C ranges from 31.98-35.54%, for drying temperature 50^{0}C from 31.67-37.12% and for drying temperature 60^{0}C from 34.00-41.78% respectively for all the drying temperature (40 to 60^{0}C), sugar concentration (40 to 60°Brix) and soaking temperature (30 to 60^{0}C). It was also revealed from the Table 13 that it was minimum 31.98% at 40^{0}Brix sugar concentration, 30^{0}C soaking

Table 12: Effect of sugar concentration, soaking temperature and temperature of osmo-convective drying on reducing sugar of dried pineapple cubes

Drying Temp	Sugar concentration 40°Brix			Sugar concentration 50°Brix			Sugar concentration 60°Brix		
	Soaking Temp 30°C	Soaking Temp 45°C	Soaking Temp 60°C	Soaking Temp 30°C	Soaking Temp 45°C	Soaking Temp 60°C	Soaking Temp 30°C	Soaking Temp 45°C	Soaking Temp 60°C
40°C	12.29^{k}	12.86^{j}	13.53^{i}	13.36^{i}	14.23^{hg}	16.44^{e}	14.22^{hg}	16.96^{d}	17.64^{c}
50°C	13.78^{hi}	13.58^{i}	15.18^{f}	14.28^{g}	15.06^{f}	17.28^{dc}	17.36^{dc}	17.20^{dc}	18.20^{b}
60°C	14.82^{f}	15.24^{f}	16.23^{e}	16.16^{e}	16.30^{e}	17.44^{c}	18.88^{a}	18.74^{a}	19.08^{a}

ANOVA

		Source of Variation	Df	SS	MS	F	P-value	F critical
SE$_1$	0.056251	Sugar Concentration	2	159.423	79.712	933.04	<.0001	2.007
CD$_{1\ at\ 0.05\%}$	0.1596	Soaking Temperature	2	43.749	21.875	256.05	<.0001	2.007
SE$_2$	0.097429	Drying Temperature	2	75.852	37.926	443.93	<.0001	2.007
CD$_{2\ at\ 0.05\%}$	0.276488	Sugar Concentration and Soaking Temperature	4	4.800	1.200	14.05	<.0001	2.007
SE$_3$	0.168752	Sugar Concentration and Drying Temperature	4	1.229	0.307	3.6	0.0116	2.007
CD$_{3\ at\ 0.05}$	0.478891	Soaking Temperature and Drying Temperature	4	7.902	1.976	23.12	<.0001	2.007
		Sugar concentration Soaking Temperature and Drying Temperature	8	7.391	0.924	10.81	<.0001	2.007
	Replication	2	0.556	0.278	3.26	0.0466		
	Error	52	4.442	0.085				
	Corrected Total	80	305.346					

Same letter are not significantly different, SE$_1$= Effect of individual Sugar concentration or soaking temperature or drying temperature on reducing sugar, SE$_2$= Effect of sugar concentration and soaking temperature, effect of sugar concentration and drying temperature, effect of soaking temperature and drying temperature on reducing sugar, SE$_3$= Combine effect sugar concentration, soaking temperature and drying temperature on reducing sugar.

temperature and 40^{0}C drying temperature and was maximum 41.78% at 60^{0}Brix sugar concentration, 60^{0}C soaking temperature and 60^{0}C drying temperature. non-reducing sugar content in pineapple cubes increased as sugar concentration and soaking temperature, and drying temperature increases.

As the sugar concentration increases from 40°B to 60°Brix, the non-reducing sugar of the dried pineapple cubes increases for all drying temperatures. However in drying temperature 40^{0}C the non-reducing sugar increases gradually form sugar concentration 40°C to 60°Brix. Similarly in drying temperature 60^{0}C non-reducing sugar increases rapidly from sugar concentration 40 to 60°Brix. Similarly as the soaking temperature of the pineapple cubes increases from 30 to 60^{0}C the non-reducing sugar increases for all drying temperature. During drying of pineapple cubes drying temperature play significant role in non-reducing sugar of the dried pineapple cubes.

Table 13 shows the ANOVA for the effect of drying temperature, sugar concentration, soaking temperature on the non-reducing sugar of the pineapple cubes. It is clear from the table that non-reducing sugar is significantly affected ($p \leq 0.05$) by the drying temperature, sugar concentration, soaking temperature. The interaction between the drying temperature, sugar concentration, soaking temperature has a significant difference on the non-reducing sugar. The interactions among independent variables significantly affected the non-reducing sugar values of pineapple cubes ($p \leq 0.05$).

6. Total sugar

Table 14 shows the effect of drying temperature, sugar concentration and soaking temperature on the total sugar (%) of the dried pineapple cubes. The total sugar for pineapple cubes were in the range of 12.29-19.08% for all the drying temperature (40, 50 and 60^{0}C), at varied sugar concentration (40 to 60°Brix) and soaking temperature (30 to 60^{0}C). Total sugar for drying temperature 40^{0}C ranges from 12.29-17.64%, for drying temperature 50^{0}C it ranges from 13.78-18.20% and for drying temperature 60^{0}C it ranges from 14.82-19.08% respectively for all the drying temperature (40 to 60^{0}C), sugar concentration (40 to 60°Brix) and soaking temperature (30 to 60^{0}C). It was revealed from Table 14 shows that, the total sugar was minimum 12.29% at 40^{0}Brix sugar concentration, 30^{0}C soaking temperature and 40^{0}C drying temperature and was maximum at 19.08% at 60^{0}Brix sugar concentration, 60^{0}C soaking temperature and 60^{0}C drying temperature. Total sugar content in pineapple cubes is increased as sugar concentration and soaking temperature, and drying temperature increases.

As the sugar concentration increases from 40°C to 60°Brix, the total sugar of the dried pineapple cubes increased for all drying temperature. However in drying temperature 40^{0}C the total sugar increases gradually from sugar concentration 40°B to 60°Brix. Similarly in drying temperature 60^{0}C total sugar increases rapidly from sugar concentration 40 to 60^{0}B.

Similarly as the soaking temperature of the pineapple cubes increases from 30 to 60^{0}C total sugar increases for all drying temperatures. During drying of pineapple cubes drying temperature play a significant role on total sugar of the dried pineapple cubes.

Table 14 shows the ANOVA for the effect of drying temperature, sugar concentration, soaking temperature on the total sugar of the pineapple cubes. It is clear from the table that total sugar is significantly affected ($p \leq 0.05$) by the drying temperature, sugar concentration, soaking temperature. The interaction between the drying temperature, sugar concentration, soaking temperature has a significant difference in the total sugar. The interactions among independent variables significantly affected the reducing sugar values of pineapple cubes ($p \leq 0.05$).

Increase in sugar concentration resulted in increase in total sugar. Similar observations were reported by Rashmi *et al.* (2005) for the total sugar content in pineapple slices which was 61.54, 65.64 and 67.17 per cent when treated in different sugar concentration i.e. 50^0, 60^0 and 70^{0}Brix, respectively. Sagar *et al.* (1999) reported the total sugar percentage in dehydrated mango slices which ranged from 56.21 to 67.30 per cent. Filho *et al.* 2015 reported that total sugar content

Table 13: Effect of sugar concentration, soaking temperature and temperature of osmo-convective drying on non-reducing sugar of dried pineapple

Drying Temp	Sugar concentration 40°Brix			Sugar concentration 50°Brix			Sugar concentration 60°Brix		
	Soaking Temp 30°C	Soaking Temp 45°C	Soaking Temp 60°C	Soaking Temp 30°C	Soaking Temp 45°C	Soaking Temp 60°C	Soaking Temp 30°C	Soaking Temp 45°C	Soaking Temp 60°C
40°C	31.98^{l}	32.48^{l}	33.56^{k}	33.74^{kj}	34.66^{ifhjg}	35.27^{feg}	35.15^{fheg}	33.78^{kj}	35.54^{fe}
50°C	31.67^{l}	33.88^{kj}	34.09^{ikj}	34.99^{ifheg}	35.96^{ced}	35.83^{ed}	34.50^{ikhjg}	36.75^{cbd}	37.12^{b}
60°C	34.00^{ikg}	35.99^{ced}	34.17^{ikhj}	37.33^{b}	36.96^{cd}	37.61^{b}	36.75^{cbd}	37.73^{b}	41.78^{a}

ANOVA

		Source of Variation	Df	SS	MS	F	P-value	F critical
SE_1	0.121195	Sugar Concentration	2	134.805	67.403	169.96	<.0001	2.007
CD_1 at 0.05%	0.3439	Soaking Temperature	2	36.992	18.496	46.64	<.0001	2.007
SE_2	0.209916	Drying Temperature	2	118.452	59.226	149.34	<.0001	2.007
CD_2 at 0.05%	0.595707	Sugar Concentration and Soaking Temperature	4	15.298	3.825	9.64	<.0001	2.007
SE_3	0.363586	Sugar Concentration and Drying Temperature	4	8.464	2.116	5.34	0.0011	2.007
CD_3 at 0.05	1.031795	Soaking Temperature and Drying Temperature	4	7.596	1.899	4.79	0.0023	2.007
		Sugar concentration Soaking Temperature and Drying Temperature	8	27.929	3.491	8.8	<.0001	2.007
		Replication	2	4.646	2.323	5.86	0.0051	
		Error	52	20.622	0.397			
		Corrected Total	80	374.805				

Same letter are not significantly different, SE_1= Effect of individual Sugar concentration or soaking temperature or drying temperature on non-reducing sugar, SE_2= Effect of sugar concentration and soaking temperature, effect of sugar concentration and drying temperature, effect of soaking temperature and drying temperature on non-reducing sugar, SE_3= Combine effect sugar concentration, soaking temperature and drying temperature on non-reducing sugar.

Table 14: Effect of sugar concentration, soaking temperature and temperature of osmo-convective drying on total sugar of dried pineapple cubes

Drying Temp	Sugar concentration 40°Brix			Sugar concentration 50°Brix			Sugar concentration 60°Brix		
	Soaking Temp 30°C	Soaking Temp 45°C	Soaking Temp 60°C	Soaking Temp 30°C	Soaking Temp 45°C	Soaking Temp 60°C	Soaking Temp 30°C	Soaking Temp 45°C	Soaking Temp 60°C
40°C	44.27^{j}	45.34^{i}	47.10^{h}	47.10^{h}	48.89^{g}	51.72^{e}	49.41^{g}	50.75^{f}	53.19^{d}
50°C	45.45^{i}	47.46^{h}	49.27^{g}	49.27^{g}	51.02^{fe}	53.11^{d}	51.86^{e}	53.95^{d}	55.32^{c}
60°C	48.82^{g}	51.23^{fe}	50.40^{f}	53.49^{d}	53.27^{d}	55.06^{c}	55.63^{cb}	56.47^{b}	60.87^{a}

ANOVA

		Source of Variation	Df	SS	MS	F	P-value	F critical
SE_1	0.109813	Sugar Concentration	2	567.298	283.649	871.18	<.0001	2.007
CD_1 at 0.05%	0.3116	Soaking Temperature	2	158.498	79.249	243.4	<.0001	2.007
SE_2	0.190202	Drying Temperature	2	380.922	190.461	584.97	<.0001	2.007
CD_2 at 0.05%	0.539762	Sugar Concentration and Soaking Temperature	4	9.144	2.286	7.02	0.0001	2.007
SE_3	0.32944	Sugar Concentration and Drying Temperature	4	11.060	2.765	8.49	<.0001	2.007
CD_3 at 0.05	0.934895	Soaking Temperature and Drying Temperature	4	3.739	0.935	2.87	0.0318	2.007
		Sugar concentration Soaking Temperature and Drying Temperature	8	19.851	2.481	7.62	<.0001	2.007
	Replication	2	3.227	1.613	4.96	0.0107		
	Error	52	16.931	0.326				
	Corrected Total	80	1170.669					

Same letter are not significantly different, SE_1= Effect of individual Sugar concentration or soaking temperature or drying temperature on Total sugar, SE_2= Effect of sugar concentration and soaking temperature, effect of sugar concentration and drying temperature, effect of soaking temperature and drying temperature on Total sugar, SE_3= Combine effect sugar concentration, soaking temperature and drying temperature on Total sugar.

in dried pineapple 19.31 at sugar concentration 50⁰B and soaking temperature 40⁰C. Expedito *et al.* 1996 studied that total sugar of osmotically dried pineapple 51.84% at 70⁰B sugar concentration and drying at 50⁰C.

Sensory evaluation of developed product

The sensory evaluation was carried out by the trained taste panel consisting of students and staff from the College of Agricultural Engg. and Tech., Dapoli. The number of panelists who evaluated osmo air dried products was 43 (23 female and 20 male).

Sensory evaluation of the Osmo-convective dried pineapple cubes shown in Table 15. Overall score of sensory characteristics ranged from 6.3 to 8.7 for all drying temperature (40 to 60°C), at varied sugar concentration (40 to 60°B) and soaking temperature (30 to 60°C). Increase in sugar concentration increased the sensory score. Maximum acceptability was observed either at the maximum level of sugar concentration and *vice versa.*

The sensory analysis of Osmo-convective dried pineapple cubes indicated that the overall acceptability of the dried pineapple cubes were highest at (sample code 'AA') at which the colour, texture, taste, flavour and overall acceptability was 8.3, 8.3, 8.4, 8.6 and 8.7 respectively. The treatment at which the sugar concentration 60⁰Brix, soaking

Table 15: Sensory Evaluation of osmo-convective dried pineapple cubes

Sample Code	Sugar concentration (⁰B)	Soaking Temp. (⁰C)	Drying Temp. (⁰C)	Sensory Parameters				
				Colour	Texture	Taste	Flavour	Overall Acceptabbility
A	40	30	40	5.8	6.1	6.1	6.3	6.4
B	40	30	50	6.3	6.6	6.1	6.3	6.6
C	40	30	60	6.2	6.1	6.3	6.3	6.5
D	40	45	40	6.1	6.3	6.4	6.5	6.5
E	40	45	50	6.1	6.1	6.8	6.0	6.5
F	40	45	60	6.5	6.3	6.7	6.6	6.5
G	40	60	40	6.4	6.2	6.4	6.4	6.4
H	40	60	50	6.0	6.1	6.3	6.0	6.3
I	40	60	60	6.6	6.7	6.6	6.8	6.7
J	50	30	40	6.3	6.5	6.2	6.3	6.8
K	50	30	50	6.4	6.4	6.3	6.3	6.7
L	50	30	60	6.8	6.4	6.3	6.6	6.9
M	50	45	40	6.4	6.5	6.2	6.4	6.7
N	50	45	50	6.4	6.7	6.4	6.8	6.8
O	50	45	60	6.7	6.9	6.3	6.9	7.0
P	50	60	40	6.7	6.3	6.6	6.7	6.9
Q	50	60	50	6.6	6.6	6.8	6.8	7.1
R	50	60	60	6.6	6.7	6.7	6.5	6.7
S	60	30	40	6.9	6.7	6.6	6.5	6.9
T	60	30	50	6.3	6.4	6.7	6.3	6.8
U	60	30	60	6.3	6.4	6.5	6.6	6.7
V	60	45	40	6.3	6.7	6.7	6.3	6.7
W	60	45	50	6.5	6.6	6.6	6.6	6.7
X	60	45	60	6.9	6.7	6.6	6.7	6.8
Y	60	60	40	6.9	6.9	7.0	6.7	7.1
Z	60	60	50	7.1	7.2	7.0	7.0	7.1
AA	60	60	60	8.3	8.3	8.4	8.6	8.7

Table 16: Sensory analysis of osmo-convective dried pineapple cubes

Source of Variation	SS	df	MS	F	P-value	F crit
(A) Colour						
Rows	561.1352	42	13.36036	9.977691	2.55E-52	1.395357
Columns	171.9345	26	6.612867	4.938574	1.66E-14	1.505771
Error	1462.214	1092	1.339023			
Total	2195.283	1160				
(B) Flavour						
Rows	446.77	42	10.63738	8.193865	1.61E-41	1.395357
Columns	146.4255	26	5.63175	4.338078	4.75E-12	1.505771
Error	1417.649	1092	1.298213			
Total	2010.844	1160				
(C) Texture						
Rows	630.7804	42	15.01858	12.64627	7.38E-68	1.395357
Columns	156.9302	26	6.035778	5.082378	4.21E-15	1.505771
Error	1296.848	1092	1.187589			
Total	2084.558	1160				
(D) Taste						
Rows	492.9543	42	11.73701	9.046524	1.02E-46	1.395357
Columns	141.1593	26	5.429206	4.184664	1.98E-11	1.505771
Error	1416.767	1092	1.297405			
Total	2050.88	1160				
(E) Overall Acceptabbility						
Rows	498.708	42	11.874	11.38669	1.28E-60	1.395357
Columns	140.155	26	5.390578	5.169348	1.84E-15	1.505771
Error	1138.734	1092	1.042797			
Total	1777.597	1160				

temperature 60^{0}C and drying temperature 60^{0}C. Table 16 shows the ANOVA for the sensory analysis of the scores obtained for osmo-Convective dried pineapple cubes at each treatment combinations. All the sensory scores was significantly different at $p \leq 0.05$.

Nutritional quality of best product

Best product sample based on the sensory scores the sugar concentration 60^{0}Brix, soaking temperature 60^{0}C which and drying temperature 60^{0}C contain best sensory scores i.e. Colour 8.3, Texture 8.3, Taste 8.4, Flavour 8.6 and Overall acceptability 8.7 respectively. TSS 32.42%, pH 4.53%, acidity 0.651%, reducing sugar 19.09%, non-reducing sugar 41.79% and total sugar 60.87%. All the best sample treatment the osmosis time was 120 min, during convective drying the cubes 360 minutes of drying time. Convective drying time and total time for this treatment 480 min.

CONCLUSION

The maximum mass reduction, solid gain and water loss obtained were 32%, 21.98 and 49.64% respectively at sugar concentration 60^{0}B, soaking temperature 60^{0}C and minimum mass reduction obtained 6.66% at sugar concentration 40^{0}B, soaking temperature 30^{0}C.

Osmotic drying of pineapple cubes the moisture content of pineapple cubes reduced by 316.24-399.54(%db) in drying time was 40-120 minutes.

Osmo-convective drying of pineapple cubes indicated that the drying was carried and in the falling rate period. The drying rate decreases with the decreases in the moisture content and it reaches to zero at the final moisture content of the osmo-convective dried of pineapple cubes. Osmotically dried cubes dried at 60^0C soaking temperature at 60^0B sugar concentration and exposed to 40^0C, 50^0C and 60^0C hot air temperature. It took around 720, 600 and 360 mintues to dry the product from an initial moisture content 120.55 (%db) to 4.89 (%db). The drying rate increases 1.494 to 2.241 kg of water removed/kg of dry matter/h as the convective hot air temperature increases from 40^0C to 60^0C at 60^0B sugar concentration and soaked at 60^0C.

The drying constant increases with increases in temperature; also it increases with increases in soaking temperature of pineapple cubes. At 60^0B sugar concentration, as the temperature of convective hot air drying increases from 40^0C to 60^0C the drying constant were 0.00822058-0.01858566, 0.00823496-0.02798883 and 0.011104647-0.02845828 (min/h) respectively.

Effective diffusivity (D_{eff}) at time (t) for osmotically dried pineapple cubes were at sugar concentration 60^0B, soaking temperature 60^0C and temperature at 40, 50 and 60 ^{0}C respectively 1.34585×10^{-7}, 1.3815×10^{-7} and 3.46359×10^{-7} m^2/s and the activation energy for pineapple cubes, which was estimated by using Arrehenius equation was found to be in the range 220.39 to 278.88 kJ/mole for all the treatment.

Osmo-convective dried pineapple cubes indicated that the best sample could be cubes soaked in at 60^0B sugar concentration at 60^0C soaking temperature and dried at 60^0C temperature of convective hot air drying resulted best sensory scores i.e. colour 8.3, texture 8.3, taste 8.4, flavour 8.6 and overall acceptability 8.7 respectively. The nutritional analysis indicated that the pineapple cubes dried at these condition have TSS 32.42%, p^H 4.53%, acidity 0.651%, reducing sugar 19.09%, non-reducing sugar 41.79% and Total sugar 60.87% etc.

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