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Osmotic dehydration of pineapple (Ananas comosus) slices

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OSMOTIC DEHYDRATION OF PINEAPPLE (Ananas comosus) SLICES

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CERTIFICATE

This is to certify that the thesis entitled ***"Osmotic dehydration of pineapple slices (Ananas comosus)"*** *submitted to the Faculty of the Post-Graduate School, Indian Agricultural Research Institute, New Delhi in partial fulfillment of* ***MASTER OFSCIENCE*** *in* ***POST HARVEST TECHNOLOGY****, embodies the results of bonafide research work carried out by* ***NASIR AHMAD HAQBEEN,Roll No. 20485*** *under my guidance and supervision, and that no part of this thesis has been submitted for any other degree or diploma.*

This assistance and help availed during the course of investigation as well as source of information have been duly acknowledged by him.

Date: September 22, 2015 ***(V. R. Sagar)***
Place: New Delhi *Chairperson*
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Dedicated To

My

Parents &

Chairman

List of Abbreviations

°B	Degree Brix
°C	Degree Celsius
ALPE	Aluminum laminated polyethylene
g	Gauge
g	Gram
HPDE	High-density polyethylene
kg	Kilo gram
kGy	Kilo gray
KMS	Potassium metabisulphite
mM	Millimole
Mpa	Mega pascal
NPLT	Normal packaging low temperature
NPRT	Normal packaging room temperature
RSM	Response surface methodology
SG	Solid gain
TSS	Total soluble solid
VPLT	Vacuum packaging low temperature
VPRT	Vacuum packaging room temperature
w/v	Weight by volume
w/w	Weight by Weight
WL	Water loss
WR	Weight reduction

Introduction

1. Introduction

Pineapple [*Ananas comosus* (Linn.) Merrill] belongs to the family of Bromeliaceae and is popularly cultivated in the tropical and subtropical regions such as Brazil, Thailand, Philippines, China, Costa Rica, India, Nigeria, Indonesia, Mexico, Columbia, Vietnam, and Kenya as the leading producers (UNCTAD report, 2010).

In India pineapple is commercially grown in the states of West Bengal, Assam, Karnataka, Bihar, Tripura, Meghalaya, Manipur, Kerala, Nagaland and Arunachal Pradesh, and spanning an area of 3.13 lakh ha with total production of 2.49 million ton. Major verities grown in India are Kew, Giant Kew, Queen and Mauritius. India is the 6^{th} leading producer of Pineapple in the world with 6.7% of world,s share with total export of 2787MT and income of Rs. 837 Lakh (NHB, 2014). Pineapple is a good source of sugar, protein and vitamins, besides other health related beneficial nutrients and minerals. It is popular among retailers and processors due to its sweet-sour taste which is a blend of sugar, maleic and citric acids. Pineapple is also rich in vitamin A, C and a source of flavoring compounds and bromelain, a digestive enzyme.

Pineapple contains considerable amount of calcium, potassium, fiber and vitamin C. It is low in fat and cholesterol and also having exceptional juiciness, vibrant tropical flavor and immense health benefits. Fresh pineapples are rich in bromelain, used for tendering meat. Bromelain has demonstrated significant anti-inflammatory effects, reducing swelling in inflammatory conditions such as acute sinusitis, sore throat arthritis and gout and speeding recovery from injuries and surgery. Pineapple reduces blood clotting and helps to remove plaque from arterial walls. It is efficient in the treatment of arteriosclerosis and anemia.

Pineapple being perishable in nature it exhibits very short shelf life (2-4 weeks) at 7-10 ºC (IHD, 2013). The postharvest loss of pineapple is reported to be about 15-20% of the total productionand growers are facing marketing problem of pineapple fruits as the ripe fruits can’t easily transported over long distances and to niche markets. During the peak production period there is always glut in the market, which leads to distress sale among the growers.

Demands for processed product are increasing day by day and consumers are looking for products which are beneficial for their health as well as carrying the taste and characteristics of the fresh commodity. When we think about long time preservation of food, drying technology is one of the most common and well known methods which is a very economical way to extend shelf life of the product (Kumar and Devi, 2011).

With the potential application of osmotic dehydration and the recent study made byresearches, osmotic dehydration technology became bold and gain more attention among other drying and dehydration methods in the food processing industry (Rastogi et al., 2002; Kumar et al., 2008). Osmotic dehydration (OD) is being widely used as about 50% dehydration process is complete during immersion of produce in hypertonic solution from the plant tissuesby partially removal of water (Kumar and Devi, 2011). The diffusion of water is accompanied by the simultaneous counter diffusion of solutes from osmotic solution in to the tissue. The rate of diffusion of water from any material depends upon factors such as temperature and concentration of the osmotic solution (Marcotte and Le Maguer,. 1992, Kumar el al., 2006). Qualityimprovement is related not only to the water removalwithout thermal stress but also to the impregnatedsolutes. With the correct choice of process variables,water removal and impregnation, it is possible toenhance natural flavour and colour retention in fruitproducts (Marcotte and Le Maguer, 1992).

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 level. Hence, there is a need to develop simple and useful technology for value added dehydrated pineapple products which can retain maximum nutrients and functional compounds and also make their availability throughout the year for human consumption. Osmotic dehydration is the useful technique which can beused in engineering process, industrial research and biological investigation for optimizingthe process system.

The present investigation will help to standardize relationship between different process variables such as concentration, temperature and vacuum pressure on osmotic dehydration which determines a set of optimum processing conditions suitable for better mass transfer kinetics of osmotic dehydration of pineapple slices.

This study will also help to pineapple growers as well as entrepreneur in development of on farm processing units for economic upliftment of the pineapple growing areas. Thus, the investigation entitled “Osmotic dehydration of pineapple slices (*Ananas comosus*) was carried out with the following objectives

Objectives:

1. Kinetic study of water loss and mass variation in pineapple cubes.
2. Evaluation of osmotic pre-treatments and drying methods for dehydrated pineapple slices.
3. Standardization of packaging and storage conditions for osmotically dehydrated pineapple slices.

Background

2. REVIEW OF LITERATURE

Pineapple is one of the well known fruit of India especially grown in hilly area like Assam to plains like West Bengal.Important verities of pineapple grown in India are Kew, Giant kew, Queen and Mauritious. Pineapple fruit has a delicious taste, aroma and flavour, blend and thus can be utilized for the development of various processed products. Pineapple is well known for its deterioration which occurs due to the enzymatic and non enzymatic factors, even it is a very tough job to safeguard its quality for the long time (Juansah*et* al., 2009).

Osmotic dehydration is a well accepted method for preservation of various fruits and vegetables. There is a great scope for processing of Pineapple into various process products, particularly dehydrated products. The international market is becoming more competitive as other pineapple growing countries are also entering in the market. The fruit and vegetable preservation industries have to look forward for the development of newer categories of products in the international market, particularly products from pineapple.

The importance of pineapple fruit has attracted the attention of a large number of research workers during the last few decades, who have generated quite good amount of information on various aspects of postharvest behavior of pineapple. The literature available on the various aspects pertained and relevant to the present investigation has been described briefly under the following heading.

2.1. Area of production

In India pineapple is commercially grown in the states of West Bengal, Assam, Karnataka, Bihar, Tripura, Meghalaya, Manipur, Kerala, Nagaland and Arunachal Pradesh, and spanning an area of 3.13 lakh ha and production of 2.49 million ton (NHB database, 2014). India is the 6th leading producer of Pineapple in the world with 6.7% of world's share with total export of 2787MT and income of Rs. 837 lakh (NHB, 2013). Some well known verities of pineapple recommended for cultivation in India are Kew, Giant kew, Mauritious and Queen.

2.2. Postharvest shelf life

Pineapple has a perishable characteristic and could be only stored for 2-8 weeks at 7-8 weeks after harvesting (NHB, 2013). Pineapple is well known for its delicious taste, aroma, flavour, blend and these characters are utilized for the development of various postharvest products. It is very tough job to safeguard its quality for the long time especially in fresh cut fruits (Juansah*et* al., 2009).

2.3. Composition of fresh fruits

Chavan and Amarowicz (2012) reported that tropical fruits including pineapple have suitable physicochemical composition which makes the fruits suitable for postharvest processing. Pineapple is a rich source of vitamin C and is being recommended to support the immune system against diseases, beside this pineapple is a good carrier of other beneficial nutrients as 100 gram of fresh edible pineapple contains 81-91g of moisture, 0.3-0.6 g of crude fiber, 37 mg calcium, 11.9 mg phosphorus, Iron 1.05 mg, carotene 0.003 -0.055mg and finally ascorbic acid of 27-162 mg.

2.3.1 Physical parameters

Harvesting of green fruit with slight yellowish color near the peduncle, with 12°B TSS and porosity of 1.5 is used as maturity indices for harvesting of pineapple which could be used for further processing. Similarly for ripened or off-green fruit minimum TSS of 12°B and porosity of 1.5 are considered for processing purposes (FAO., 2005).

2.3.2. Chemical parameters

Pineapple is a good source of sugar, protein and vitamins besides other health related beneficial nutrients and minerals. It is popular among retailers and processors due to its sweet-sour taste which is sugar, maleic and citric acids blend, it is also rich in vitamin A, C and a source of flavouring compounds and bromelain, a digestive enzyme (Joy., 2010).

2.3.2.1. Moisture

Appiah *et* al. (2012) studied the chemical composition of two verities of MD2 and smooth Cayenne for consumer acceptability in Ghana.Moisture content of Smooth Cayenne increased from 684.0 g kg^{-1} (unripe) to 693.0 g kg^{-1}during ripening (full ripe) which represents a 1.3% increase of moisture content with ripening. Similarly MD2 showed an increase of 1.8% from 798.0 g kg^{-1} to 812.0 g kg^{-1} in the moisture of the fruits. Moisture content has been reported to decrease of 4% to 15% at last 2 week before full ripening (Joy., 2010). Inyang and Agbo (1995) reported that moisture content of pineapple ranges from 69 to 89.5%.

2.3.2.2. Total soluble solids

A general increase has been reported in total soluble solids in two varieties of Smooth Cayenne and MD2 of pineapple during ripening. Whereas TSS increased from 117.0 g kg^{-1} to 126.0 g kg^{-1} in MD2, and from 97.0 g kg^{-1} to 114.0 g kg^{-1} in Smooth Cayenne increased representing increases of 7.7 % and 17.5 % respectively (Appiah *et* al., 2012). Nicoleti*et* al. (2001) investigated the differences of fresh and osmotically pre treated pineapple, and they have reported the total soluble solids for ripen Smooth Cayenne variety of pineapples from 12 to 16 °B and moisture content from 83 to 87% (wet basis).

2.3.2.3. Titratable acidity

Citric and malic acids are the two major organic acids in pineapple (Saradhuldhat & Paull, 2007). During the ripening acids are involved in protein synthesis which results decreasing in total titratable acidity (Lacey *et* at., 2009). Total titratable acidity for Smooth Cayenne shown a decrease of (2.5 g kg^{-1}) form 4.9 g kg^{-1} in unripe to 4.1 g kg^{-1} in full ripe, while in case of MD2 in unripe it decreased from 2.5 g kg^{-1} to 1.4 g kg^{-1} in full ripe (Appiah *et* at., 2012).

2.3.2.4. Sugars

The sugar and acid ratio of the both MD2 and Smooth Cayenne verity of pineapple fruit pulps increased with increase in ripening progress. The sugar and acid ratio increased from 46.8:1 to 90.0:1 in MD2 and from 19.8:1 to 27.8:1in Smooth Cayenne increased with full ripening. Fruit acids are degrade during the ripening which causes increasing in sugar content and increase in (sugar-acid) ratio (Shashirekha & Patwardhan, 1976). (Colaric *et* al., 2005) reported that the sugar and acid ratio contributes a unique flavour of fruits, which is an indicator for commercial and organoleptic ripeness. There is a very low level of acids in overripe fruits and therefore it causes lack of characteristic of flavour (OECD, 2011). The carbohydrate content of fresh pine apple has been reported 13.7 g/100g (Joy., 2010).

2.3.2.5. pH

Sorencen. (2014) studied the pH level in pineapple at 10 different countries including India and reported that in pineapple pH ranges from 3.2 to 4, the US-FDA-Center for Food Safety & Applied Nutrition also reports that in pineapple pH is varying from 3.2 to 4.0.

2.3.2.6. Ascorbic acid

Asdarina. (2006) reported that ascorbic continent in fresh pineapple ranges from 20 to 40 mg/100 gr. A study of ascorbic acid degradation in pineapple by application of osmo-dehydration followed by air drying in Nigeria had reported the ascorbic acid value of a ripen fruit 32.5 (mg/100g) of the fresh pineapple. Karim and Adebowale (2009) studied the ascorbic acid degradation in pineapple during air drying and osmotic pre treatment.

2.3.2.7. Carotenoids

Joy (2010) reported that the carotene content of fresh pineapple 0.003 to 0.055 mg/100g.

2.3.2.8. Total Phenol content

Mongi *et* al. (2015) reported that *Smooth cayenne* verity of fresh pineapple fruit contains 289.9 ± 4.2 (mg GAE/100g) total phenols, they also reported that thermal drying methods are decreasing the total phenolics content in pineapple and tunnel drying had more total phenolics retention compared to the direct cabinet drying and mixed cabinet drying.

2.3.2.9. Enzymatic Browning

Gonzalez *et* al. (1993) reported that pineapple juice used as anti-browning agent inhibited the enzymatic browning up to 26% in apple slices. Similarly Chaisakdanugull *et* al. (2007) reported that banana slices dipped in pineapple juice had the similar inhabitation of enzymatic browning with the banana cut slices dipped in 8 mM ascorbic acid.

2.4. Pre-treatments

2.4.1. Blanching

Blanching as a pre treatment for osmotic dehydration shown a significant effect on drying rate and drying time of pineapple slices. The increase in blanching temperature and time combinations resulted extension in drying times (Agarry *et* al., 2013). The use of microwave drying prior to the application of osmotic dehydration and freeze drying resulted a positive synergistic effect on mass transfer. This pre treatment could reduce the energy utilization throughout the complete dehydration processes up to 61.3% measured as (kJ/kg) of obtained product (Pardo and Leiva, 2010). Anna Chwastek (2014) reported that preliminary preparation of fruits for osmotic dehydration has a significant effect on kinetics of the process.

2.4.1.2. Water Blanching

Gudapaty *et* al. (2010) reported that the combination of pre-osmotic dehydration with conventional water blanching before drying reduced the time of drying and a better preservation quality of dehydrated Indian gooseberry was obtained and reduced the degradation of ascorbic acid.

2.4.1.3. Steam Blanching.

Ioannou and Ghoul (2013) reported that steam blanching had a significant effect on prevention of enzymatic browning in pineapple slices, they also reported that 100 ºC steam temperature for 3 min was found ideal for pineapple steam blanching.

2.4.2. Size and shape

Shape of the fruit or product impregnated with syrup for further osmotic dehydration equally important as it is very efficient for osmotic dehydration (Rastogi *et* al., 2004). Kumar and Devi (2011) studied the different parameters (slice thickness, temperature, sugar concentration and osmotic agent) of osmotic dehydration of pineapple slices, they have reported optimum parameters for osmosis process as 6mm of slice thickness at 63 °B, 55 °C and 0.05% KMS.

2.4.3. Osmotic agent

Additives such as sucrose, ascorbic acid and calcium lactate have been found to affect the water loss from the product, especially in pineapples during osmotic dehydration (Silva *et* al., 2014), but the efficiency of food additive depends on the nature of food additive, it was found that weight reduction, water loss of the product as and solids gain were higher when sucrose was used as an osmotic agent. Silva *et* al. (2014) reported that addition of calcium lactate and ascorbic acid to the syrup solution used for osmotic dehydration increased the impregnation and sensory quality and decreased the energy consumption of the osmotically dehydrated pineapple slices. The effect of osmotic agents on quality of raisins studied by Bawa and Gujral (2000) showed that solid gain and water loss varies in each agent (honey and sugar) and rate of water loss and solid gain varies with concentration of syrup.

The rate of water loss, weight reduction and solid gain was higher in papaya slices while soaked in sugar solution (Aouar *et* al., 2006). Nicoleti *et* al. (2001) studied the different concentration of salt solution used as osmotic agent on different temperatures and air velocities of pre treated pineapple slices.

2.4.4. Temperature and concentration of osmotic solution

Temperature nearly 45 °C has been found optimum for osmotic dehydration of pineapple slices (Ramallo *et* al., 2012). Syrup concentration has been shown to affect the shrinkage and appearance of the product in osmotic dehydration of fruits and vegetables (Correa *et* al., 2011). Karim and Adebowale (2009) studied on sugar concentration on ascorbic acid content of pineapple.He reported that the higher ascorbic acid retention was observed in 40% sucrose syrup 2.6mg/100g while it was slightly lower 2.42 mg/100g when the syrup concentration was increased to 60%.Sridevi and Genitha (2012) studied on five different sugar concentration, temperature and time period for osmotic dehydration of pineapple, result showed that there was weight reduction 20.37%, solid gain 13.36% & water loss 30.09% when the sugar concentration was 44.05°B, temperature 38.2°C and processing time 128.7 min respectively. In another study different parameters (slice thickness sugar concentration, temperature and osmotic agent), Kumar and Devi (2011) reported 63 °B of sugar at 55 °C were found optimum for osmotic dehydration treatments, when slice thickness and KMS were found less effective on water loss and solid gain.

2.4.5. Solid - syrup ratio

Pardo and Leiva (2010) studied the syrup to solid ratio of sucrose solution 60 °B for osmotic dehydration of pineapple slices and they found 1:5 w/w optimum ratio. Pedapati and Tiwari (2014) reported the significant effect of 1:2 solid to syrup ratio of sugar solution for osmotic dehydration of guava on the weight loss, yield and moisture loss, the sugar concentration used was 50, 60 and 70 °B and time of 4, 18 and 24 hour.

2.4.6. Immersion time

Sridevi and Genitha (2012) studied effect of time duration for immersion of pineapple slices at osmotic dehydration affecting the weight reduction, solid gain & water loss, they reported that 128.7 min was found optimum soaking time duration.

2.4.7. Agitation

Agitation during osmotic dehydration is increasing the water loss capacity, this found to be a key factor in osmotic dehydration process (Rastogi *et* al., 2002).

2.4.8. Mass transfer rate

Saputra (2001) reported that the sugar concentration, temperature, and length of immersion have a significant effect on the mass transfer rate of osmotic dehydration in Queen verity of pineapple. They found that the highest rate of mass transfer optimized at the sucrose concentration of 70%, temperature 50 °C and immersion time of 9 hours. Kumar and Devi (2011) studied that the mass transfer kinetics of osmotic dehydration of pineapple slices had a significant effect on mass transfer rate while the slice thickness and KMS percentage had least effect on the transfer rate. Anna Chwastek (2014) studied the mass transfer rate increased with the use of ultrasound, high hydrostatic pressure, vacuum osmotic dehydration and pulsed electric field.

2.5. Osmotic dehydration

Osmotic dehydration is an effective method for preservation of fruits and vegetables such as banana, guava, fig, sapota, pineapple, mango, apple, grapes, pumpkins, carrots, etc. with retention of initial fruit characteristics *viz* aroma, texture, colour and nutritional composition. Compared to air or vacuum drying process it consumes less energy as can be conducted at low or ambient temperature (Chavan and Amarowicz., 2012). The intelligent use of osmotic dehydration conditions is very important as osmotic dehydration secures the quality and affects the further drying of the product.

Sagar *et* al. (2010) reported that new technologies like dehydration, vacuum drying, freeze drying, superheated steam drying, heat pump drying and spray drying have great scope for the production of quality dried products and powders, these new technologies have greater efficiency than the traditional methods of preservation like sun drying which is more prone to contamination and leads to poor quality than this methods.

Sridevi and Genitha (2012) studied the optimization of osmotic dehydration of pineapple based on response surface methodology design. They reported that the desired osmosis diffusivity was observed on these levels 38.2°C, 128.7 min and 44.05°B of sugar to be (30.09%; 13.36% & 20.37%) respectively.

2.6. Methods of drying

2.6.1. Sun drying

Sun drying is widely used for preserving fruits in Africa this causes the product to lose its nutritional value and due to the cell damage occurs in fruit tissues (Lombard *et* al., 2008). Bala *et* al. (2001) reported that the quality of solar tunnel dehydrated pineapple was much better as compared to sun drying.

2.6.2. Cabinet drying

Karim and Adebowale (2009) reported the positive effect of tray load and air flow at cabinet dryer when the temperature and humidity was automatically controlled by dryer. The optimum conditions of various parameters for osmotic dehydration of carrot slices were reported as sugar concentration 30 to 50 $^{\circ}$B, 30 $^{\circ}$C and 40 $^{\circ}$C osmotic solution temperature and 120 min of osmosis duration to be further dried at 65 $^{\circ}$C for 4 hrs at cabinet dryer (Gani and Kumar., 2013).

2.6.3. Air drying

Galvez *et* al. (2012) reported that there was a significant effect of air velocity on the kinetics of dehydrated apple slices such as rehydration ratio, compositional changes like anti oxidants and phenols.

2.6.4. Vacuum drying

Vacuum processing is one of the best non thermal processing options to extend the shelf life of fruit and vegetables (Paz *et* al., 2003) reported that water activity was low when the mango slices were dried under the vacuum at 674 m-bar combined with 50 $^{\circ}$B. A vast range in changes in solid gain, water loss and colour have been reported by (Valencia *et* al., 2011) when melon was dried at high and low level of pressure under vacuum.

Kingsly *et* al. (2009) studied the effect of high pressure processing on texture and drying behavior of pineapple slices. They have reported that with the implication of high pressure, hardness is reduced. They also reported that there was reduction in chewiness of the sample, when the pressure treatment was applied at range of 500 MPa. Rastogi *et* al. (1998) reported significant influence of different pressures on the kinetics of osmotic dehydration of pineapple slices, when a pressure of 70 and 600 pascal were applied.

2.6.5. Microwave drying

Gani and Kumar. (2013) reported that the temperature of 30 °C and 40 °C, 30 to 50 °B sugar concentration and soaking duration 120 min were found optimum for further microwave oven drying at an input power of 20W for 22 min for osmotic dehydration of carrot slices. Correa *et* al. (2011) reported that there was a significant effect of osmotic dehydration on moisture reduction but it was not significant in the complete process using microwave vacuum drying.

2.7. Packaging and storage

Highest loss of vitamin C has been reported in pineapple cubes after 6 moth of storage at room temperature when the cubes were pre-treated with invert sugar and packed at HDPE (Pual *et* al., 2014).

Sagar *et* al. (2009) reported that the 200g high density polyethylene (HDPE) bags as packaging material were better for extending the shelf life of osmotically dehydrated papaya up to 6 months at ambient temperature.

Saxena*et* al. (2009) recommended hurdled technology with combination of osmotic dehydration, gamma radiation dose of 1 kGy and infrared drying for osmotically dehydrated pineapple to reduce the microbial load to below detectable limit. Pineapple slices were found to have intermediate moisture, good colour, texture and sensory acceptability after 40 days of storage.

Sagar and Khurdiya (1999) reported that good quality and airtight containers can be used to store osmotically dried products. Aluminum foil, laminated polypropylene pouches were suggested as desirable packing materials. The osmotically dried papaya packed in high density polyethylene(HDPE) pouches reported to be acceptable with slightly changes after 6 month of storage at room temperature (Ahemed and Choudhary, 1995; Chavan and Amarowicz, 2012).

2.8. Quality parameter

2.8.1. Physical parameters

2.8.1.1. Dehydration ratio

Pedapati and Tiwari (2014) studied the effect of solution concentration and immersion time on osmotic dehydration of guava, they found that dehydration ratio was increased with the increase at sugar concentration and increase in dehydration time.

2.8.1.2. Rehydration ratio

The osmotic solution of 50°B of sugar for 4 hrs and drying temperature of 60°C for 27 hrs were found to retain a better rehydration capacity in osmotically dehydrated pineapple. Rehydration was done at 90°C for 15 min at room temperature (Fasogbon *et* al., 2013). Correa *et* al. (2011) reported that there are several factor affecting the rehydration ratio of pineapple slices such as solution concentration and immersion time and the porosity of the sample as well.

2.8.2. Chemical parameters

2.8.2.1. Moisture

Gani and Kumar (2013) reported that increase in syrup concentration and temperature had significantly affected the rate moisture out take from carrot slices during osmotic dehydration, they also reported that moisture content was increased during the storage of osmtically dehydrated carrots. The moisture content was continuously increasing with the increase of storage period in osmotically dehydrated mangoes (Sagar and Kumar., 2009). Paul *et* al. (2014) reported that increase in period of storage had a significant effect in increasing the moisture content of osmotically vacuum dried pineapple cubes.

2.8.2.2. Total soluble solids (TSS)

Sujatha *et* al. (2014) reported that there wasincrease in TSS in the osmotically treated dried pineapples during storage. The increase in TSS of dehydrated mango slices during storage period was reported by (Abdelgader and Ismail, 2011)

2.8.2.3. Titrtable acidity

Sagar and Kumar (2009) reported that titratable acidity decreased with increase in sugar concentration and time of soaking.Abdelgader and Ismail (2011) also reported that titratble acidity was decreased in dehydrated mango slices during storage.

2.8.2.4. Sugar

Sagar and Kumar (2010) reported that sugar content increased in osmotically dehydrated mango slices under different storage conditions as the period of storage increased. Silveira *et* al. (1996) reported that the sugar content of osmo-air dried pineapple was increased from 51.95% to 57.85% during four month of storage. Increase in the sugar content during the storage has been reported by (Sujatha *et* al., 2014) in osmotically dehydrated pineapple. Increase in sugar content of osmotically vacuum dried pineapple cubes during 6 months of storage was reported by (Paul *et* al., 2014).

2.8.2.5. Ascorbic acid

Karim and Adebowale (2009) reported that ascorbic acid has been reduced in pineapple slices from 32.5mg/100g in fresh pineapple to 2.7 in control and 2.6 in osmosed pre treated. Sujatha *et* al. (2014) reported a significant reduction in acidity of osmosed-dried pineapple in 3 month of storage which was 84.1% retention for non radiated samples and 78.9% for radiated samples.

2.8.2.6. Carotinoids

Gani and Kumar (2013) studied the effects of osmotic dehydration on physico-chemical characteristics of carrot Slices and they reported an increase in beta carotene content of carrot with increase in sugar concentration. El-Masry (1998) reported that the osmo-air dehydrated mango contained higher total carotenoid 5mg/100g than air dehydrated one (3mg/100g).

2.8.2.7. Total Phenols

Mancilla *et* al. (2013) reported that the combination of higher pressure vacuum with osmotic dehydration had significantly increased in the total phenlos content in osmotically dehydrated strawberries. Sen *et* al. (2015) reported that the total phenlics content of dried apricot decreased during the period of storage.

2.8.2.8. Non-enzymatic browning

The low water activity can prevent or delay the non-enzymatic browning similarly the osmosis agents are sticking to the sides of the dehydrated products and this causes the prevention of non-enzymatic browning. Sujatha *et* al. (2014) reported that the osmotically dried pineapple was free from non-enzymatic browning with fresh like colour till 3 month of storage.

2.8.2.9 Sensory quality

Osmotic dehydration treatment retained flavour, color and texture of original fresh fruits, this may be due to prevention of enzymatic browning thus making it possible for good color retention (Sujatha *et* al., 2014). Torreggiani (1993) reports that osmotic dehydration was more effective to minimize the damages of colour, flavour and texture of the product than hot air drying. Osmotically dehydrated raisins using honey as osmotic agent scored more for its good flavour while the sample soaked in sugar solution was more acceptable for its better colour and appearance and over all acceptability (Bawa and Gujral, 2000).

2.9. Microbial quality

Zapata *et* al. (2011) reported that immersion of pineapple slices in sugar solution in 45 °B containing 2.48% citric and 44.99°C for 4 to 6 hrs retained high sensory score and reduced in microbial counts of more than two log cycles.

Ramarjuna and Jayaraman (1980) studied the microbial quality of intermediate moisture of osmo-dehydrated banana stored at 0°C and 37 °C, they reported that at 0 °C the total plate count was 250 to 300 colonies/g, whereas at 37 °C it was negligible and product was microbiologically safe for direct consumption. Sujatha *et* al. (2014) reported that use of different hurdles in osmotically dehydrated pineapple products were found very effective in term of microbial control during storage. In osmotic dehydration due to high solute concentration there was less microbial problem (Rastogi *et* al., 2014). Saxena*et* al. (2009) reported the microbial load was below detectable limit in osmotically dehydrated pineapples while the samples were treated with 1 kGy gamma radiation. Sapata *et* al. (2009) reported that there was reduction in microbial load with reduction of pH in osmotic solution during dehydration process.

Materials and Methods

3. MATERIALS AND METHODS

The present investigation entitled **"Osmotic dehydration of pineapple (*Ananas comosus*)"** was undertaken at the Division of Food Science and Postharvest Technology, Indian Agricultural Research Institute, New Delhi during 2014-15.The treatment details and methodology for execution of the studies have been presented in this chapter.

3.1. Experiment 1

Kinetics studies on pineapple cubes.

3.1.1. Treatments:

Treatment 1**:** Sugar concentrations(50, 60, and 70)^{o}Brix

Treatment 2: Temperature of sugar solution(30, 40 and 50) ^{o}C

Treatment 3: Vacuum pulses (atmospheric "760" mm Hg, 435 mm Hg and 110 mm Hg) pressures

Time - 20, 40, 60, 90, 120, 150, 210 and 240 min

3.1.2. Methodology

The ripe pineapples having 12±0.5 °B were procured from Azadpur market New Delhi for kinetic study. The pineapples were peeled with the help of knife to remove the flesh and peeled pineapples were cut into slices(10 mm thickness), core was then removed and cubes were made into (1x1x1cm^3) size. The samples were weight and immersed in osmotic solution and sample to solution ratio was kept 1:4 (w/v). Accordingly as per experiment at requirements about 216 samples were treated with different concentration of sugar solution ranging from 50 ºB to 70 ºB.

The vacuum oven was used to maintain the 3 different levels of temperature and pressure, the pressure was applied initially for 15 min to the samples and then the pressure was released to room pressure however the temperature was kept constant during the osmosis process. At the end of each time period (20 – 240 min) the samples were taken out and smoothly surface of the pre-treated sample was cleaned with the help of tissue paper and subjected to measurethe weight reduction (WR), water loss (WL) and solid gain (SG) immediately (Plate 1). After that all the samples were kept at 110 °C for 3-5 hrs for dehydration up to final moisture continent of 5.22% in finished product. Thus the mass variation (ΔM) and water loss (ΔW) were calculatedaccording to Eqs (1 and 2) Silva *et* al. (2014).

$$\Delta M = \frac{M - M_0}{M_0} \times 100 \qquad (1)$$

$$\Delta W = \frac{(MW_w) - M_0 W_0 W_w}{M_0} \times 100 \qquad (2)$$

Where $M_0$is the mass at the initial time

M is the mass at time t

W_0 is initial water content

W_w is the water content at time t

Kinetic modeling

Non-linear regression analysis was done using Statistica software (STATISTICA 9) to determine the best model to explain the variation in moisture ratio with time duration during osmotic dehydration of pineapple cubes. More than ten models were applied to fit the kinetics of moisture ratio in pineapple cubes (Table 3.1.1).

Based on degree of fit as determined using variance explained, coefficient of regression, per cent loss and visual fit, three models (Diffusion model; Wang and Singh model and Logistic model) were selected. Further, root-mean-square-error (RMSE) and chi-square (χ^2) tests were conducted for these models.

3.2. Experiment 2

Evaluation of osmotic pre-treatments and different drying methods for dehydrated pineapple slices.

3.2.1. Treatments

Treatment 1**:** Sugar concentrations - 50, 60, and 70ºB.

Treatment 2: Temperature of sugar solution - 30, 40 and 50ºC

Pineapple cubes for osmotic dehydration

Drying of cubes for moisture kinetics

Plate 1: Preparation of cubes for kinetics of water loss

Preparation of slices for osmotic dehydration

Before drying

Osmotic dehydration under vacuum

After drying

Plate 2: Osmotic dehydration of pineapple slices

	Mathematical equation	References
	MR=exp(-kt)	Lewis (1921)
	$MR=exp(-kt^n)$	Page (1949)
age	$MR=exp(-(kt)^n)$	Corzoet al. (2008)
and	MR= a.exp(-kt)	Henderson and Pabis, (1961), Ne Kushwah, (2009)
	MR= a.exp(-kt)+(1-a).exp(-kat)	Karaaslan&Tuncer (2008)
	$MR=a.exp(-kt)+b.exp(-k_1t)$	Mohapatra&Rao (2005)
c	MR=a.exp(-kt)+c	Kingsly& Singh (2007)
	$MR=1+a.t+b.t^2$	Wang & Singh (1978)
.	$MR=a.exp(-kt)+(1-a).exp(-k_1t)$	Vermaet al. (1985)
and	$MR=a.exp(-kt)+b.exp(-k_1t)+c.exp(-k_2t)$	Vega-Galvejet al. (2010)
	$MR=a+bt+ct^2$	Sharma & Prasad (2004)
	$MR = b/(1 +a.exp^{-kt})$	Chandra and Singh (1995)

Treatment 3: Vacuum pulses (atmospheric “760” mm Hg, 435 mm Hg and 110 mm Hg) pressures

Time - 180 min

Added preservative: 0.5% KMS

3.2.2. Methodology

The fresh pineapple (ripen) were procured from Azadpur market, New Delhi, and stored at Division of Food Science and Postharvest Technology, IARI, New Delhiat 8 °C temperature for overnight. Next day the fruits were cleaned andabout 3 cm bottom portion was removed with the help of knife. Pineapple corer was used to take out the core and flesh of pineapple fruit was cut into slices(1 cm thickness), the slices were further treated in sugar solution containing 0.5% KMS for osmosis dehydration at the ratio of 1:4 (w/v). As per pre standardized protocol from previous experiment osmotic dehydration was conducted for 180 min followed by draining the samples. The osmotically dehydrated pineapple slices were further dried at the tray drying oven model (MAC-MSW-216) at 55 ±2 °C up to 10 hrs and different moisture levels of less than 10 %. Once the drying was complete the osmotically dehydrated pineapple slices were evaluated for physical and biochemical analyses.

The response surface methodology (RSM) design was applied to reduce the number of experiments as well as to improve statistical interpretation possibilities (Plate 2). The Box-Behnken Design was applied for RSM study. The responses were the 6 parameters (moisture, colour, texture, appearance, odour and taste) for acceptability of dehydrated pineapple slices.

3.3. Experiment 3

Standardization of packaging and storage conditions for osmotically dehydrated pineapple products.

3.3.1. Treatments

Mode of pack: With and without vacuum

Storage temperature: Ambient & low temperature (7±1°C)

Packaging material: Aluminium laminated pouches

Time intervals for analyses: 30, 60, 90 & 120 days

3.3.2. Methodology

The pineapples were procured from Azadpur Mandi, New Delhi, and the fruits were selected from single stall with the same size and same maturity stage (ripen). Pineapples were cleaned, peeled and core was removed with the help of pineapple corer and knife, treatments were applied as per standardize condition based on previous experiment (70 °B, 50 °C and 435 mm Hg pressure with the 0.5% of KMS) for 180 min under vacuum followed by 10 hrs further drying in cabinet drier at the 55 ±2 °C up to moisture level of 5.22 % (Plate 3). The dried pineapple slices were then packed in aluminium laminated polyethylene (ALPE 260g) bags 6x4 inch size, normally packaging with 30±1g dehydrated material and 15±0.5g for vacuum packaging. The dehydrated pineapple slices were packed into aluminium laminated pouches ALP and stored at about 7±1 °C at low temperature and room temperature of about 28 ±3 °C for storage study up to 120 days (Plate 4). The slices were withdrawn for analysis at interval of 30 days for following observations.

3.4. Observations recorded

3.4.1. Weight Reduction

The reduction in weight WR of the dehydrated pineapple slices was estimated using the following equation (3) (Sridevi and Genitha, 2012).

$$WR = \frac{M_0 - M}{M_0} \tag{3}$$

where,

M_0 is initial mass of sample in grams

M is mass of the sample after dehydration

3.4.2. Water loss

Water loss (WL) in osmotically dehydrated pineapple slices was recorded with the help of equation (4) (Sridevi and Genitha, 2012).

Plate 3: Osmotically dehydration pineapple slices with different treatments (RSM)

Plate 4: Storage of dehydrated pineapple slices

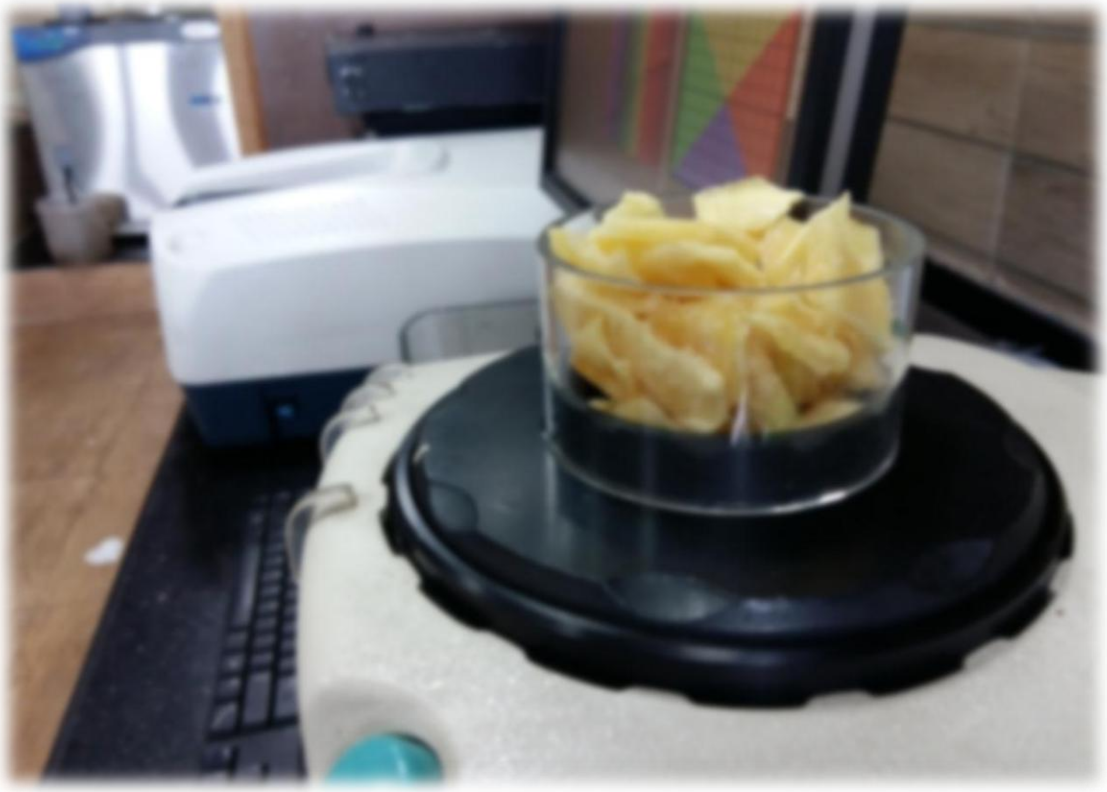


Plate 5: Colour measurement

$$WL = \frac{\{(W_0 - W_t) + (S_t - S_0)\}}{W_0} \times 100 \qquad (4)$$

Where,

W_0 is initial weight taken for osmosis dehydration in (g)

W_t is the weight of osmotically dehydrated sample at time t in (g)

S_0 is the initial dry matter in (g)

S_t is the dry matter after osmotic dehydration for particular time

3.4.3. Solid Gain

The solid gain (SG) in osmotically dehydrated pineapple slices was determined using the following equation (5) Sridevi and Genitha (2012).

$$SG = \frac{S_t - S_0}{W_0} \times 100 \qquad (5)$$

Where,

S_t is the dry matter after osmotic dehydration at particular time

S_0 is the initial dry matter in (g)

W_0 is initial weight of slices taken for osmosis dehydration in (g)

3.4.4. Hunter colour analysis

The colour was determined using Hunter Lab System (model: Miniscan XE PLUS).The colour value was expressed as *L**, a* and b*. The lightness co-efficient, *L**, ranges fromblack = 0 to white =100. The coordinate (*a**, *b**) locate the colour on a rectangularcoordinate grid perpendicular to the *L** axis. The colour at the grid origin (*a**= 0, *b**= 0) isachromatic (grey). On the horizontal axis, positive *a** indicate a hue of red purple andnegative *a** of bluish green. On the vertical axis, positive *b** indicates yellow and negative *b**blue. Calibration of the instrument was done with black and white tiles, and verification ofaccuracy against standard tiles was performed before evaluation. To measure surface colour,four readings were taken from randomly selected pieces of dried pineapple. Finally, the value wascalculated from the mean of four determinations for each sample (Plate 5).

3.4.5. Ascorbic Acid

Ascorbic acid determined by titration method by using 2, 6-dicholorophenol-indophenol dye (Ranganna, 1999)

Reagents

3% Metaphosphoric acid (HPO_3): For preparation of 3% metaphosphoric acid, 3g HPO_3 pellets weighed and dissolved in 100ml of distilled water.

Standard stock solution of ascorbic acid: 100 mg of 1- pure ascorbic acid power was weighed and dissolved in 100 ml with 3% $HPO_{3.}$ 10 ml from this stock solution was diluted to 100 ml for titration.

Dye solution: Dye solution was prepared from60 mg of the sodium salt of 2, 6-dichlorophenol-indophenol in approximately 160 ml of distilled water containing 42 mg of sodium bicarbonate. Solution was cooled and diluted with distilled water up to 200 ml. Dye solution was stored in refrigerator and standardized each and every day before estimation.

Procedure:

Standardization of Dye

5 ml of standard ascorbic acid solution was taken in a conical flask and 5 ml of HPO_3 was added into it. A micro burette was filled with dye solution and ascorbic acid solution titrated with the dye solution until a pink colour persisted for about 15 seconds. The dye factor was determined i.e., mg of ascorbic acid per ml of the dye, using the following formula:

$$\text{Dye Factor} = \frac{0.5}{\text{Titre value}}$$

Preparation of sample

- 5g of dehydrated pineapple sample was taken and crushed with mortar and pestle in 3% metaphosphoric acid and volume was made 100 ml with 3% $HPO_{3,}$ samples were filtered with whatman filter paper No.1 and10 ml aliquot sample was taken in 100 ml conical flask and titrate with dye solution.

Calculation of Ascorbic Acid:

Ascorbic acid content of osmotically dehydrated pineapple samples was calculated as given below formula:

$$\text{Ascorbic acid content (mg /100g)} = \frac{\text{Titre value} \times \text{Dye factor} \times \text{Volume made up}}{\text{Wt. of the sample taken} \times \text{Aliquot wt. of sample taken for estimation}} \times 100$$

3.4.6. Moisture (%)

The moisture content was determined by drying a known weight of the sample at 50-60 °C in hot air oven to a constant weight and expressed as per cent (Ranganna, 1999).

$$\text{Moisture (\%)} = \frac{\text{Fresh weight} - \text{dry weight}}{\text{Fresh weight}} \times 100$$

3.4.7. Water Activity

Water activity A_w was measured using a water activity meter (Hygrolab, Rotronic) (Plate 6).

3.4.8. Texture

The texture of the dehydrated samples was found using Stable Micro System model TA.XT Plus machine, following the method measurement of hardness by Bourne (1975). Two disc samples were taken and pressed to remove the space between the slices, puncture test compression mode was carried using needle P/2n with speed of 1.5 mm/sec for penetration of (zero mm) in test sample. The texture expert S.W was used to express penetration force in gram.

3.4.9. Total phenols

The total phenolics content was determined by the Singleton and Rossi (1965) with some modifications. 5 ml of dehydrated pineapple slice was crushed and mixed in 10 ml of 80% ethanol. The homogenate was then centrifuged at 10000 × g for 20 min at 4°C and supernatant was used for assay of total phenols. Then 2.8 ml of distilled water, 200 µl sample and 0.5 ml of 2 N Folin-Ciocalteau reagents was added. After 3 min, 2 ml 20% of Na_2CO_3 was added into it. The prepared solution was then kept for sometime till it became blue-black. Then absorbance was measured at 750 nm using 1 cm cuvette in a perkin-elmer UV-VIS lambda 25 spectrophotometer. Gallic acid (0 - 800 mg l-1) was used to produce standard calibration curve. The total phenolics content was expressed in milligram of Gallic acid equivalent per 100 mL dried pineapple (mg Gallic acid equiv. 100 mL-1).

Reagents

1. 80% Ethanol
2. 05 ml of 1N Folin-Ciocalteu reagents**-** 2ml FCR in 2 ml of double distilled water
3. 2ml of 20% Na_2CO_3 (Sodium carbonate) **-** 20g sodium carbonate add in 80ml of distilled water
4. Standard gallic acid

3.4.10. Total Sugar

A known weight of sample was taken and clarified by the addition of 2.0ml of 45% led acetate. Later the led acetate was neutralized by the addition of 2.0ml of 22% potassium osxlate solution. The clarified solution was made to a known volume with distilled water and filtered. The total sugars were estimated by hydrolyzing the clarified solution with 5ml of concentrated hydrochloric acid for 48 hours at ambient temperature. The hydrolyzed solution was neutralized with alkali (40% NaOH) and it was titrated against Fehling`s solutions using methylene blue as an indicator (Plate 7). The sugars were calculated as given below (Ranganna, 1997)

$$\text{Total Sugar (\%)} = \frac{\text{Factor x dilution x 100}}{\text{Titrate Value x Wt. of sample}} \text{ X } 100$$

3.4.11. Microbial Analysis

The microbial examination was done at division of Microbiology, IARI, New Delhi to identify the fungal, bacteria and yeast in the product during storage. The product was examined for the presence of the above organisms as per standard procedures. One gram aliquot of the product was diluted (10^{-2} to 10^{-6}) and then one ml of the suspension was incorporated into petridishes followed by puring potato dextrose agar (yeast).Martin Rose Bengal Agar (fungi) and SPCA (bacteria). The inoculated plates were incubated for 5-6 days at 28 °C (Pierson *et* al., 1986). These plates were examined for the presence of micro-organisms.

3.4.12. Organoleptic evaluation

The sensory quality evaluation of the product was done by a semi trained panel of 7 judges from FS&PHT, IARI, and aged 25- 45 years from both of the genders, using a 9 point Hedonic scale (Amerine *et*al., 1965). The overall rating was calculated by averaging the scores. Samples which obtained a score of 5.5 and above were considered as acceptable (Plate 8). The organoleptic score and its rating were as follows:

Organoleptic score	Rating
9	Like extremely
8	Like very much
7	Like moderately
6	Like slightly
5	Neither like nor dislike
4	Dislike slight
3	Dislike moderately
2	Dislike very much
1	Dislike extremely

3.4.13. Total carotenoids content

Principle

Total carotenoids content of pineapple fruit was determined by the method of Roy (1973) with some modifications. For this, 5 ml of dehydrated pineapple slice was crushed in acetone in a pestle-mortar until the fruit pulp became colourless. Then the extracted solution was poured into a separating funnel. To it, petroleum ether and small amount of sodium sulphate solution were added and shaken rigorously. Then the separating funnel was kept undisturbed to separate the carotenoids from acetone to petroleum ether layer. After that, coloured solution was separated in a 50 ml volumetric flask and the volume was adjusted with petroleum ether. Finally, the sample absorbance was measured at 452 nm in a spectrophotometer, using petroleum ether as blank. The results were expressed as mg L^{-1}.

Reagents

- Sodium sulphate (5%): Weighed 5 gm sodium sulphate powders. First dissolved in small amount of distilled water and then dissolved in 100 ml of double distilled water in volumetric flask.
- Acetone (GR)
- Petroleum ether (60º-80ºC GR)

3.4.14. Statistical design and analysis of data

The experiments were laid out in both RSM (Box-Behnken Design model) for the 2st objective, and factorial CRD design for other parameters the data obtained from the experiments were analyzed as per design through SPSS software version 14 and the results were compared from ANOVA table by calculating the C.D.

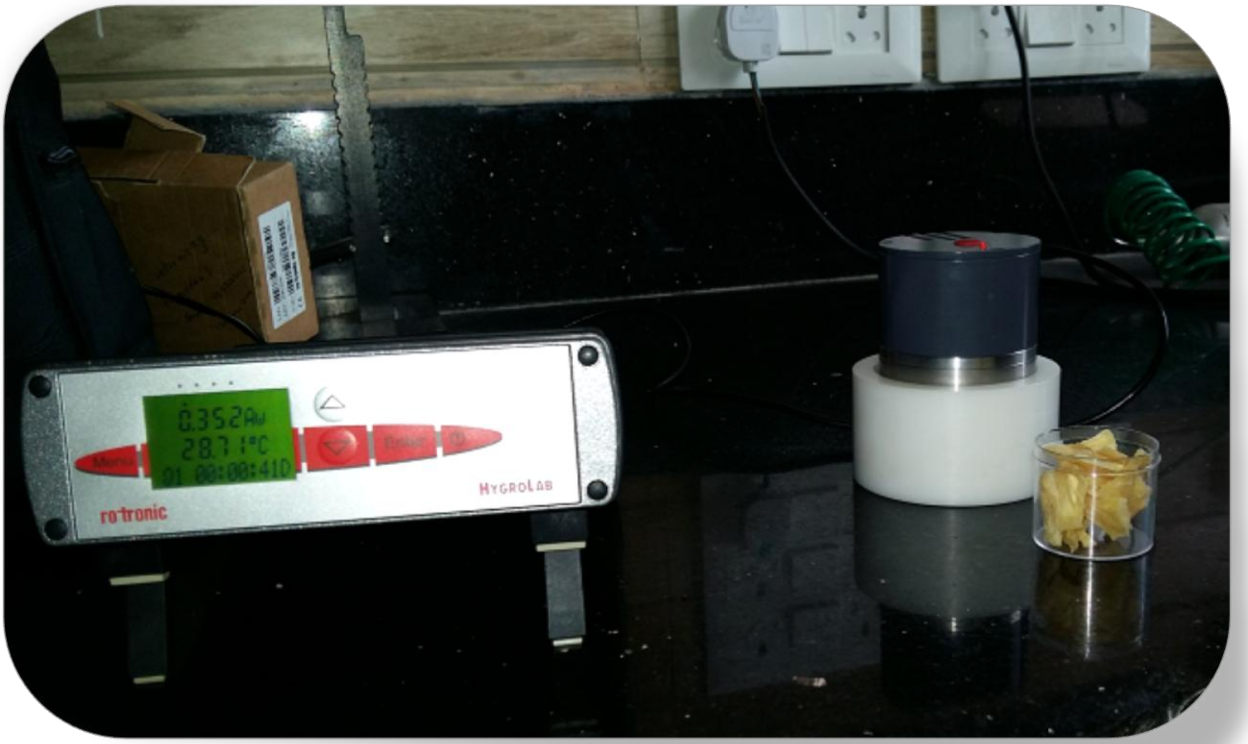
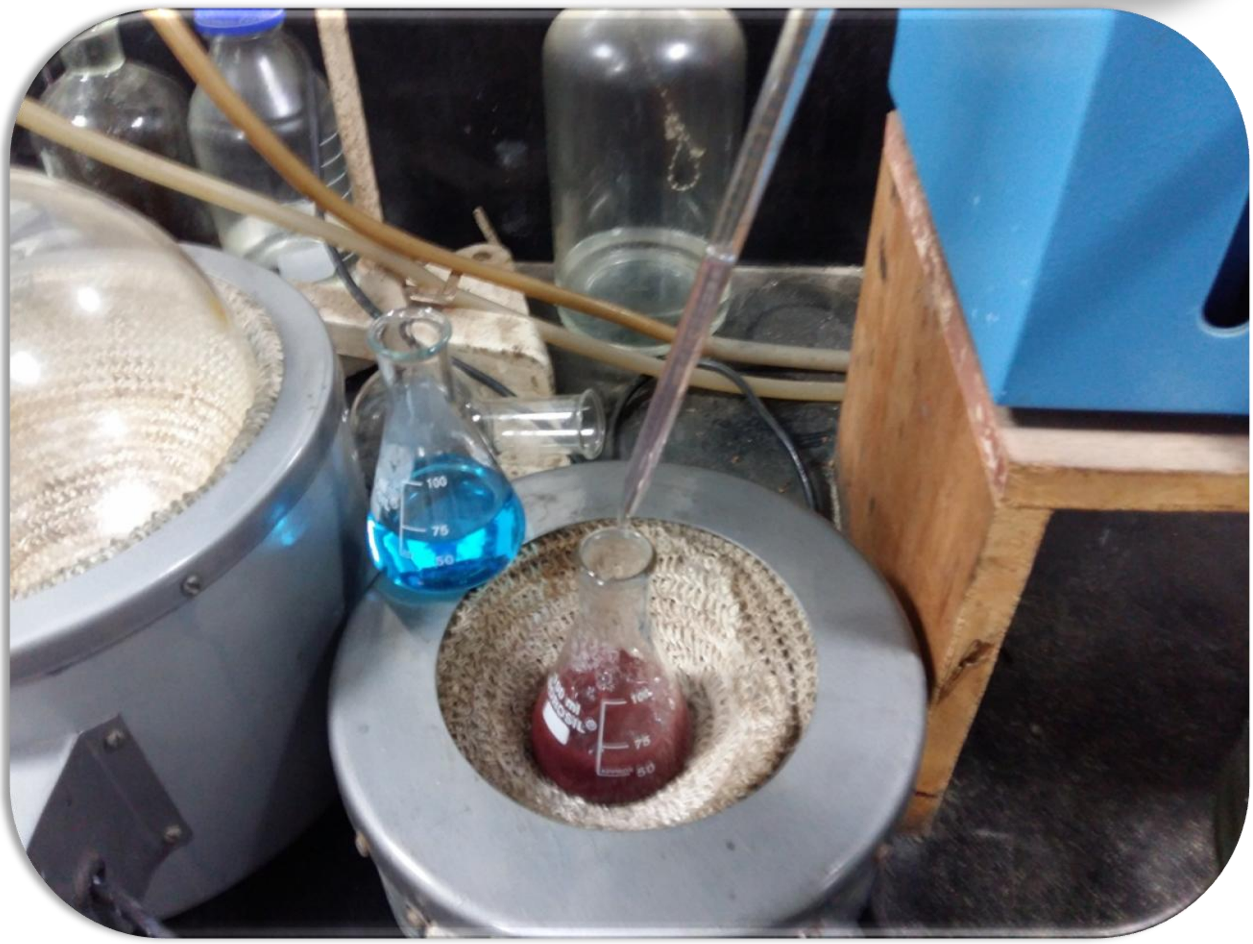


Plate 6: Water Activity (A_w)

Plate 7: Sensory evaluation


Kimwipes


100
75
50

Results

4. RESULTS

The present research investigations entitled ‘Osmotic dehydration of pineapple slices (*Ananascomosus*)’ were carried out in the Division of Food Science and Postharvest Technology, ICAR- Indian Agricultural Research Institute, New Delhi-110 12, India during the year 2014-15. For the investigation, three experiments were planned and executed. The results of these investigations have been presented as under.

4.1. Kinetic study of pineapple cubes on water loss and mass variation.

4.1.1. Effect of concentration and temperature of osmotic solution on water loss behaviour of pineapple cubes.

Atmospheric (760 mm Hg) Pressure

Water loss of pineapple cubes at atmospheric pressure increased with increase in time of dipping in all three sugar concentrations and temperature of osmotic solution up to 150 min and then decreased. However maximum water loss using 50 °B solution was observed 34.4% at the temperature of 40 °C followed by 50 °C and 30 °C (Fig. 4.1.1-a). Similarly the pineapple cubes treated with 60 °B sugar concentration the water loss was recorded 43% at 50 °C after 120 min and the lowest at 30 °C (Fig. 4.1.1-b). In case of samples treated with 70 °B sugar solution recorded maximum water loss 46% at 40 °C after 150 min and lowest in the cubes treated with 70 °B at temperature of 30 °C (Fig. 4.1.1-c). While comparing all three concentrations of sugar solution and temperature of solution 70 °B at 40 °C was found more effective for reduction of more water loss followed by samples treated with 70 °B at 50 °C and 30 °C.

Vacuum pressure 435 mm Hg

The rate of water loss increased steadily at pressure level of 435 mm Hg, till 120 min after that a static equilibrium was attained. The highest water loss 33% was found to in 70 °B at 40 °C (Fig. 4.1.2-c), wherein mass equilibrium was attained in 150 min. Water loss for pineapple cubes osmosed in 60°B solution, closely followed this value at 30% in the same duration of osmosis. At lower concentrations of osmotic solution 50°B, the equilibrium was attained in 210 min.

Vacuum pressure 110 mm Hg

At higher vacuum level of 110 mm Hg the reduction in water loss increased with increase in time of dipping in all three sugar concentrations with respect to temperature range up to 210 min at the sugar concentration on 50°B and 60°B and up to 150 min at the sugar concentration of 70 °B. The water loss was more at 40 °C under the both 60 °B and 70 °B sugar solutions followed by 30 °C and 50 °C (Fig. 4.1.3 a-c). However the rate of water loss reduction was observed faster up to 100 min in all three concentrations of sugar and temperature and after that it slowed down.

4.1.2. Effect of concentration and temperature of osmotic solution on mass variation behaviour of pineapple cubes.

Figures(4.1.4 to 4.1.6) demonstrate the nature of mass variation occurring at atmospheric pressure (under agitation) and at pressure levels equivalent to 435mm Hg and 110mm Hg. These figures indicate a rapid increase in percentage of mass variation, followed by steady decline at the later stages of osmosis. Thus indicating that rate of water loss was greater than rate of sucrose gain. Figures (4.1.4 to 4.1.6) show the initial increase of mass variation with time during the osmoticdehydration process, reaching a reduction from ~23% to13-16% of the initial mass after 4 h of osmotic dehydration.

Atmospheric pressure

Mass variation occurred highest at 70°B followed by 60 °C and 50°B concentration of osmotic solution. The effect of temperature was also clearly indicated that higher rate of mass variation occurring at 50 °C and least at 30 °C. At 70 °B, the peak was attained in 120 min, while at 50 and 60 °B it appeared in 150 min. Higher mass variation was observed with increase in temperature from 30 °C to 50 °C which may be due to lower viscosity of osmotic solution and higher vapour pressure differential at higher temperature at the surface of mass transfer (Fig. 4.1.4 a-c).

Vacuum 435 mm Hg

Similar results were observed at 435 mm Hg pressure with respect to temperature and degree brix. However, at 40 °C, although the rate of mass variation was initially lower than the corresponding variation at 50 °C, higher percentage in mass variation was observed in later stages of osmosis. Trend for equilibration time was similar to

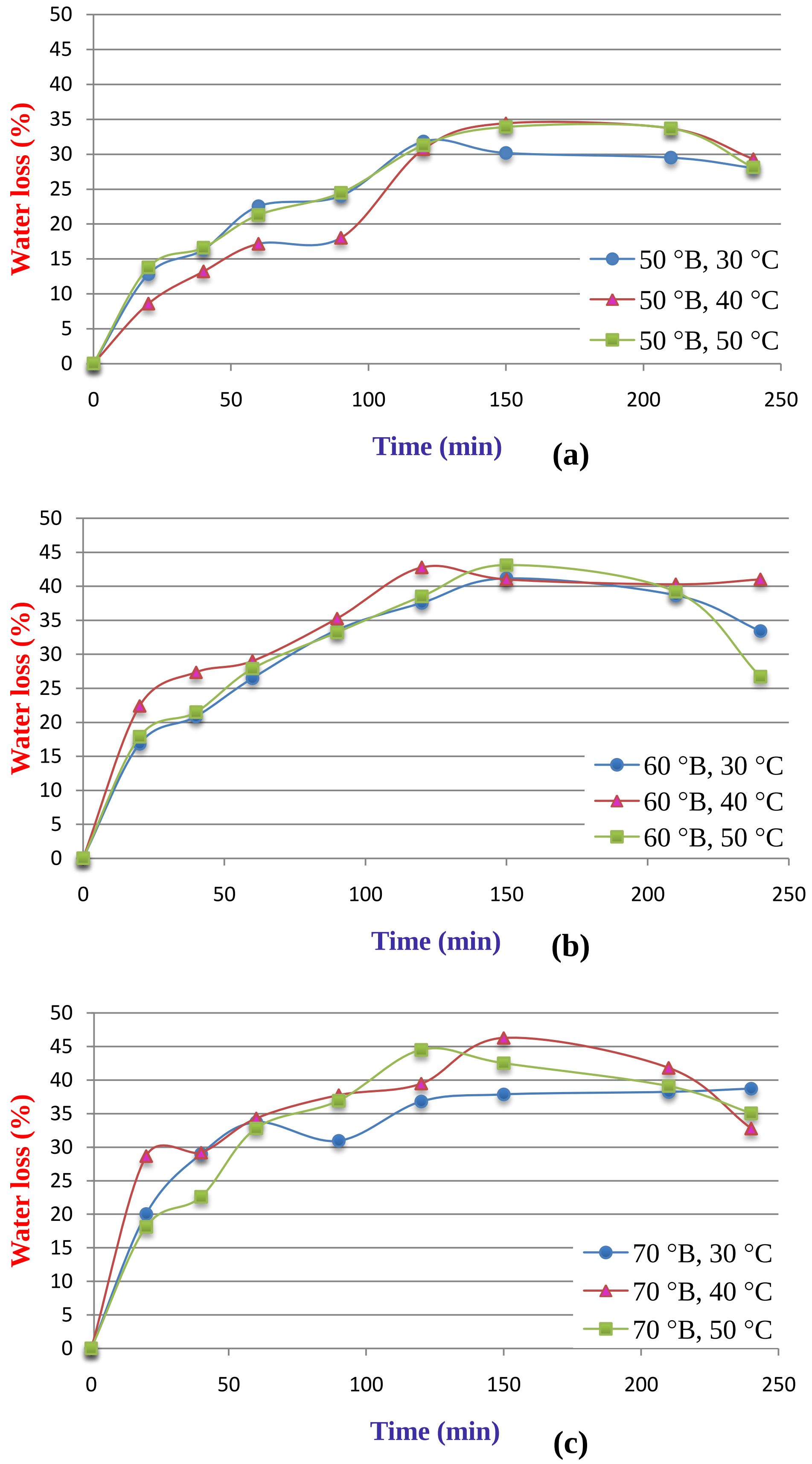


Fig. 4.1.1: Effect of sugar concentration and temperature on water loss at atmospheric (760 mm Hg) pressure.

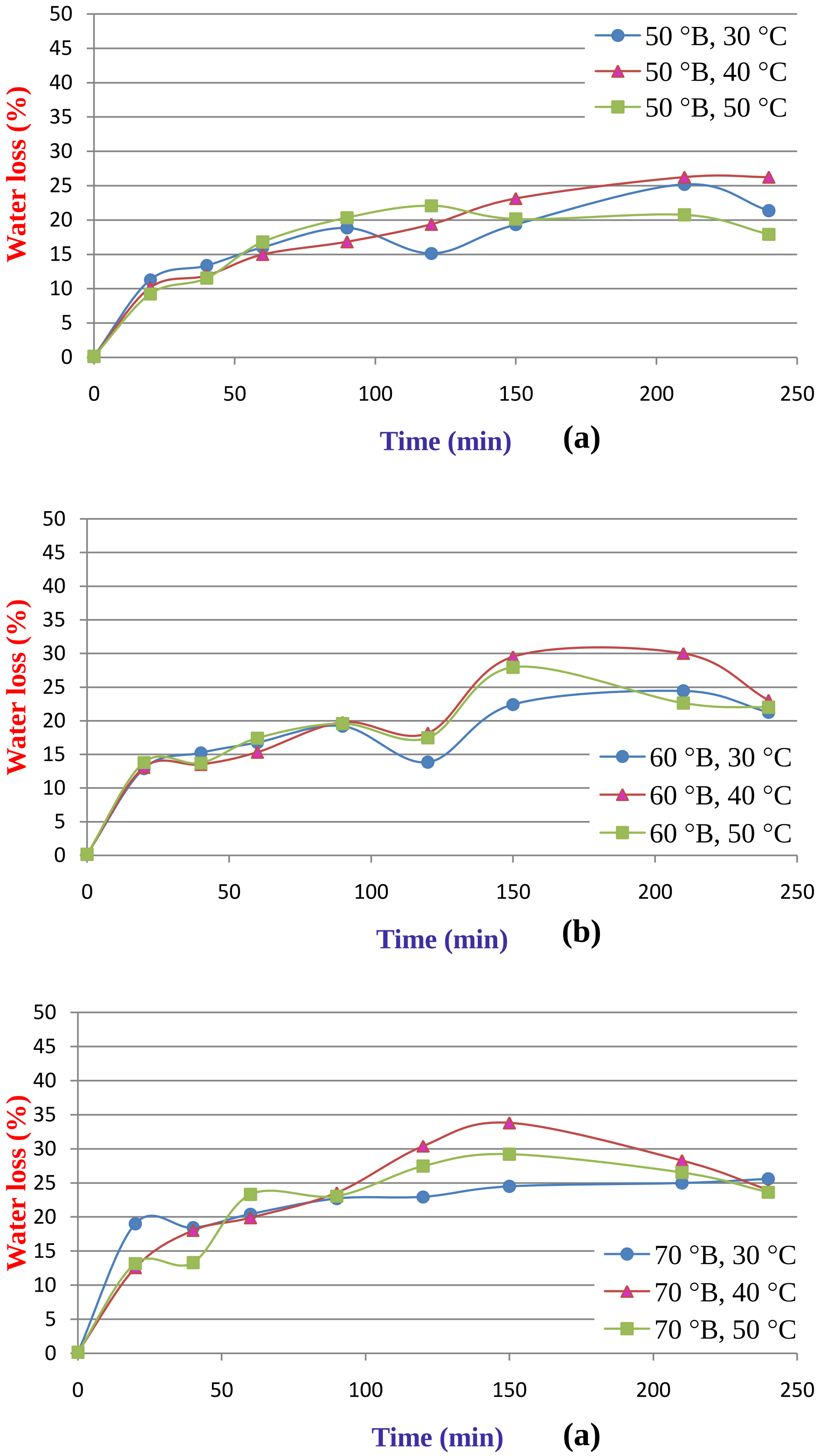


Fig. 4.1.2: Effect of sugar concentration and temperature on water loss at 435 mm Hg pressure.

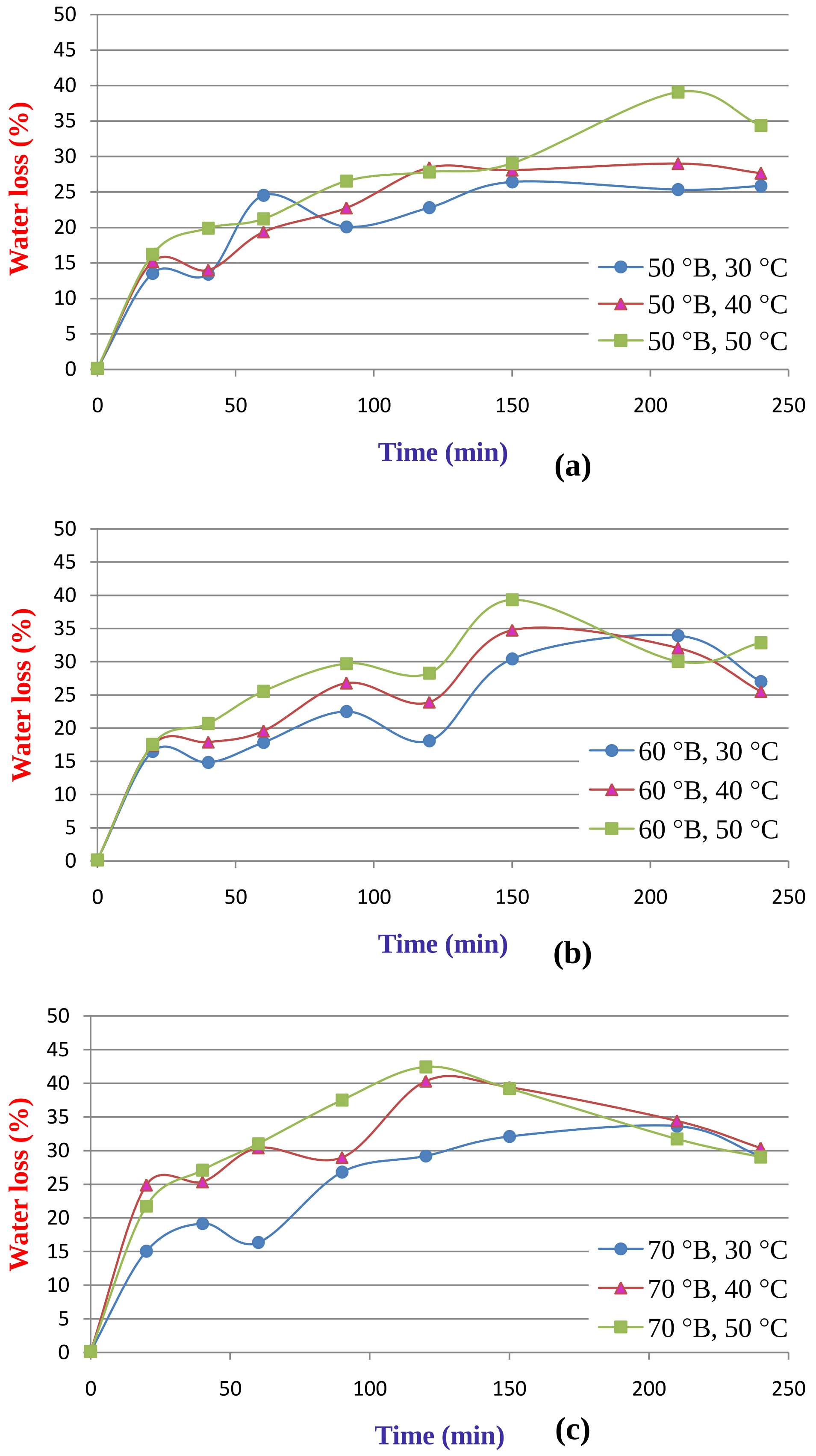


Fig. 4.1.3: Effect of sugar concentration and temperature on water loss at 110 mm Hg pressure.

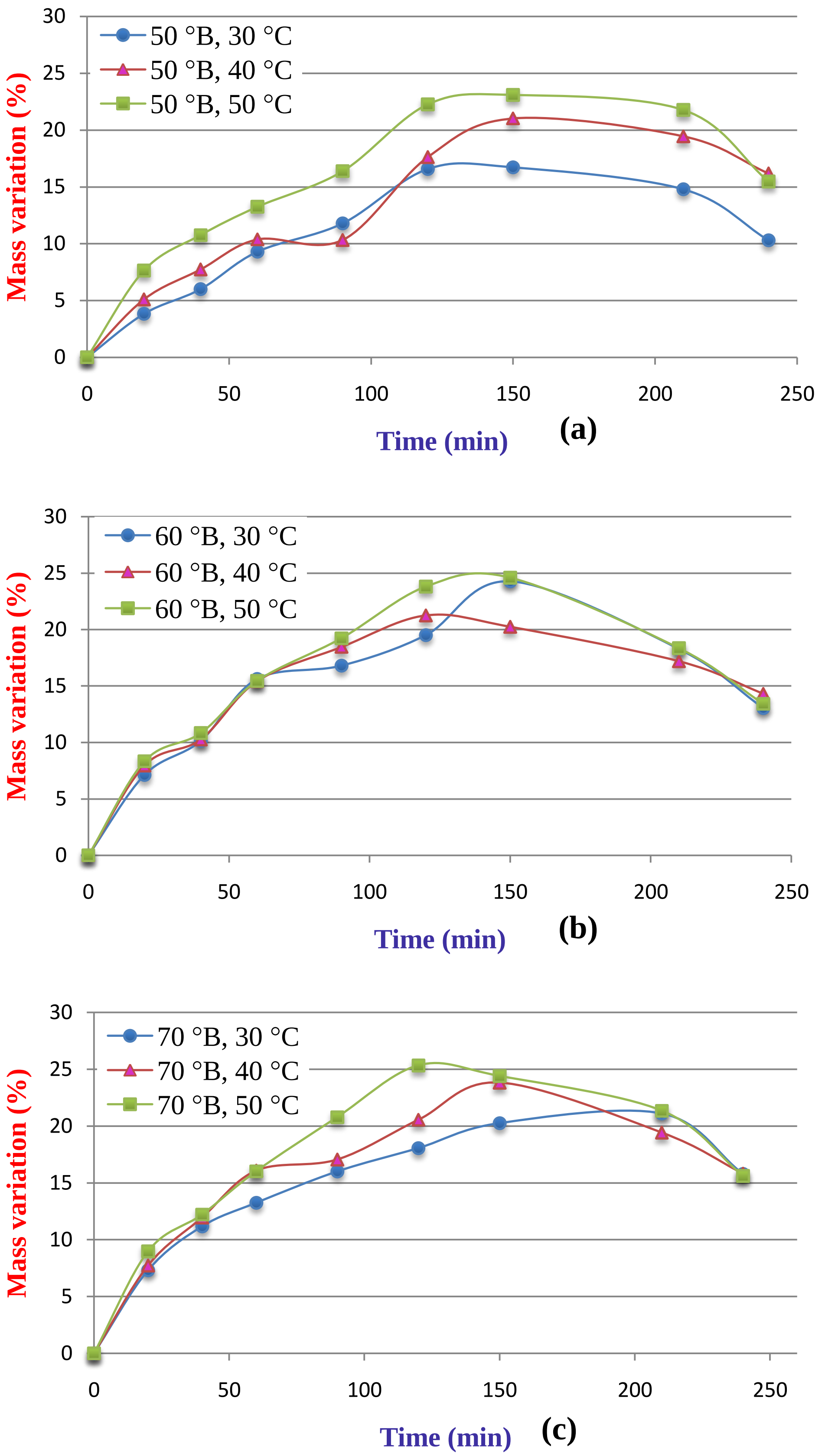


Fig. 4.1.4: Effect of sugar concentration and temperature on mass variation at atmospheric pressure.

water loss at 50-60 °B the peak was attained in 210 min, however at the sugar concentration of 70 °B the peak time shifted to 150 min.

The maximum mass variation of 14% was recorded for 50 °B solution at temperature of 40 °C with a osmosis duration of 210 min while the lowest variation was observed at 30 °C for the same duration of time (Fig. 4.1.5-a). At 60 °B the maximum mass variation of 17%was recorded in 150 min (Fig. 4.1.5-b). Similarly, maximum mass variation of 20% was observed at 70 °B sugar solution followed by 16% mass variation at 40 °C in 150 min of duration respectively (Fig 4.1.5-c).

Vacuum 110 mm Hg

The data presented for mass variation at 110mm Hg of pressure Fig. 4.1.6 (a-c) shows that time of immersion, temperature and concentration of solution were directly proportional to the mass variation in pineapple cubes. Upon increase in duration there was upward curve initially observed up to a certain period of time and then it reversed. This may be attributed to unequal rates of mass and solute transfer in the dynamic state to each other. The permeability of membranes, allow higher moisture loss than solute gain, thus the downward trend in mass variation has been observed in all conditions. At 50 °B, the rate of mass variation (%) was proportional to temperature and maximum variation was 20% at 50 °C in 210 min and minimum at 30 °C during same duration (Fig. 4.1.6-a). While at 60 °B and 70 °B, the peak of mass variation 22% was observed at 150 min and slow down, which clearly shows the mass transfer potential during osmo-dehydration of pineapple cubes.

The mass variation of samples treated with 70 °B was the maximum 23% at 50 °C with a duration time of 120 min whereas at 30 °C temperature mass variation was slowed down (Fig. 4.1.6-c). The comparison of three different concentrations, temperatures and pressure levels shows that 70 °B at 50 °C at 110 mm Hg had the most efficient mass variation followed by 70 °B at 40 °C at 110 mm Hg.

4.1.3 Drying kinetics of pineapple cubes with respect to osmosis solution temperature

Fig. 4.1.7 depicts the RMSE values for fit of data using the three models at various pressure levels of osmosis. Since lowest value of RMSE indicates least difference in the observed and computed values by the particular model, it was imperative that logistic model gave the best predicted values for the observed data.

Similarly, from chi-square test, which is considered a better indicator of degree of fit to non-linear estimations, it was observed that logistic model gave the least values

(Fig. 4.1.8). To further test the efficacy of this model, parity chart was drawn for observed and predicted values (Fig. 4.1.9). An excellent fit to the model was hence observed.

Fig 4.1.10 shows the drying kinetics of pineapple cubes at atmospheric pressure and depicts the effect of temperature on moisture ratio of pineapple cubes immersed in 50 °B osmotic solution. From the (Fig. 4.1.10), it can be clearly seen that at 40 °C, the rate of moisture loss was faster than at 50 °C followed by at 30 °C. Although higher rate of moisture loss may be explained by the gradual loss of moisture from pineapple cubes at 50 °C, Similar observations were recorded for pineapple cubes immersed in 70 °B solution at atmospheric pressure (Fig. 4.1.11).

4.1.4. Parameters of the logistic model as function of temperature, °Brix and pressure.

Table 4.1.1 present the variation in coefficients "a*" and "b*" of pineapple cubes during osmotic dehydration at varying levels of sugar concentration in osmotic solution with respect to temperature 30-50 °C at atmospheric pressure.

The variation in coefficient "b*" was found to decrease with increase in temperature of osmotic solution in all sugar concentrations (Figures 4.1.12 and 4.1.13). Also "b*" values decreased with increase in osmotic concentration (higher °B of osmotic solution). Being directly proportional to moisture ratio, higher value of "b*" indicates higher moisture retention and vice versa.

Thus, at higher osmotic potential lower water retention in osmosed pineapple cubes was recorded, while at lower concentration of osmotic solution, the pineapple cubes retained higher moisture at same temperature of osmotic solution and the variation ranged (0.62 to 0.78) with respect to all concentrations of solution and temperatures (Fig. 4.1.13). Similar trend was observed for coefficient "a*" value. However at 60 °B and 50 °C, unusually low moisture ratio 0.67 was observed (Fig. 4.1.14).

At 435 mm Hg, the variation in coefficient "b*" ranged from 0.78 to 0.85 under all conditions of varying temperature and osmotic solutions (Table 4.1.1). With increase in temperature from 30 °C to 50 °C a wide variation in range of coefficient "b*" was observed at 50 and 60 °Brix whereas with increase of solution concentration to 70°B the variation was very low and it ranged only 0.78 to 0.81. With respect to all 3 temperatures the variation coefficient range of "b*" increased with the increase in concentration of osmotic solution and increasing the temperature of solution.

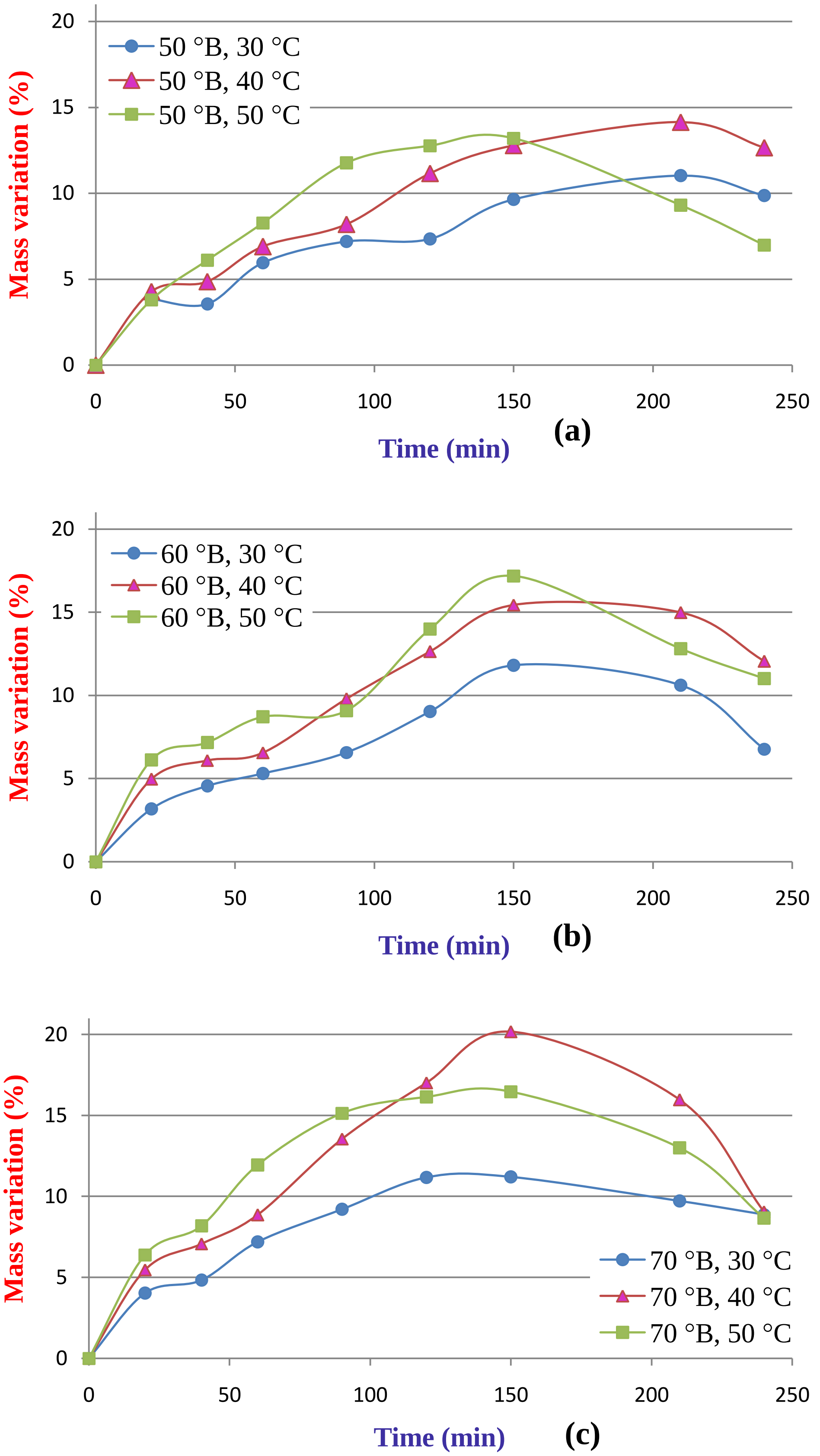


Fig. 4.1.5: Effect of sugar concentration and temperature on mass variation at 435 mm Hg pressure.

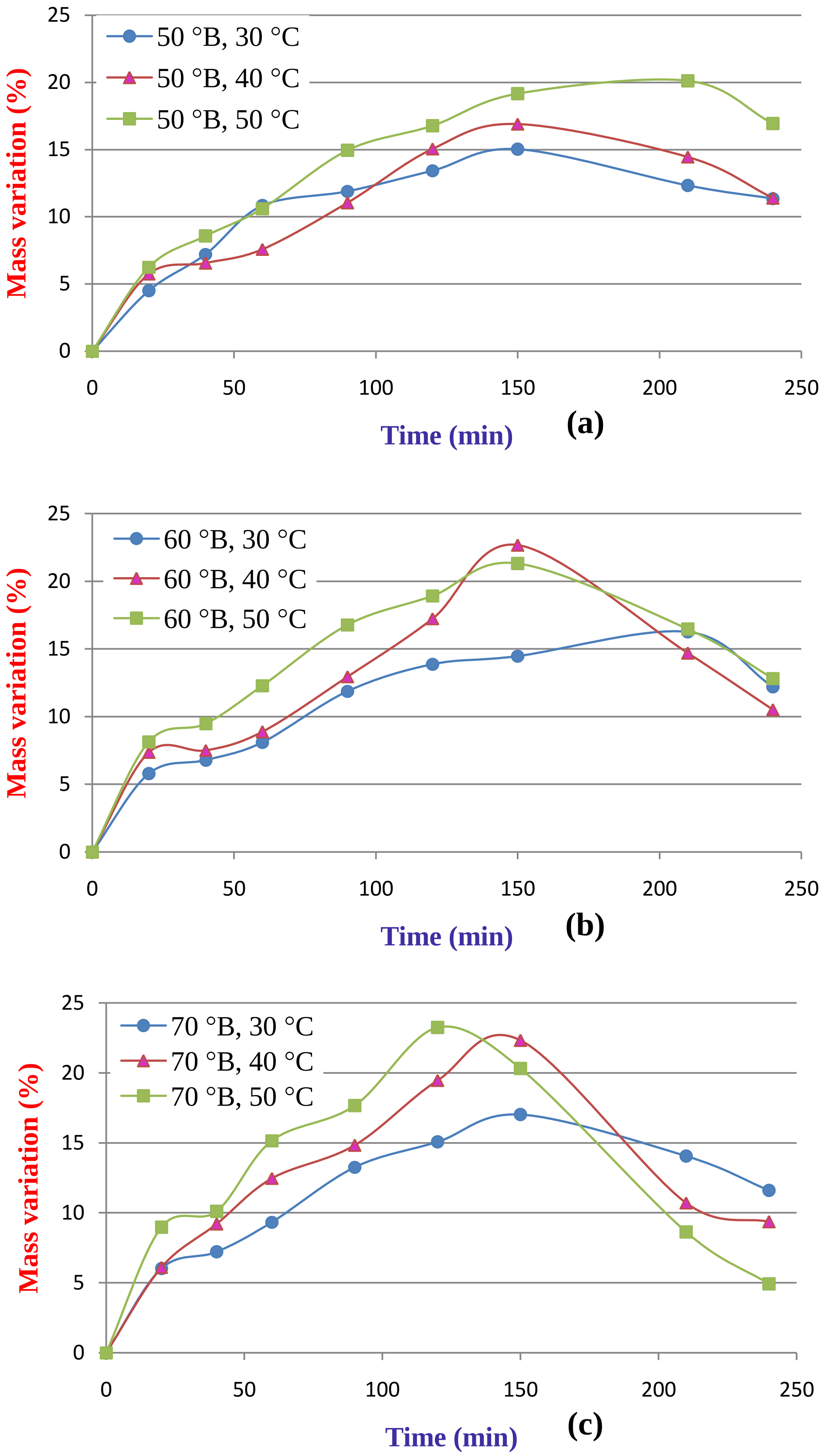


Fig. 4.1.6: Effect of sugar concentration and temperature on mass variation at 110 mm Hg pressure.

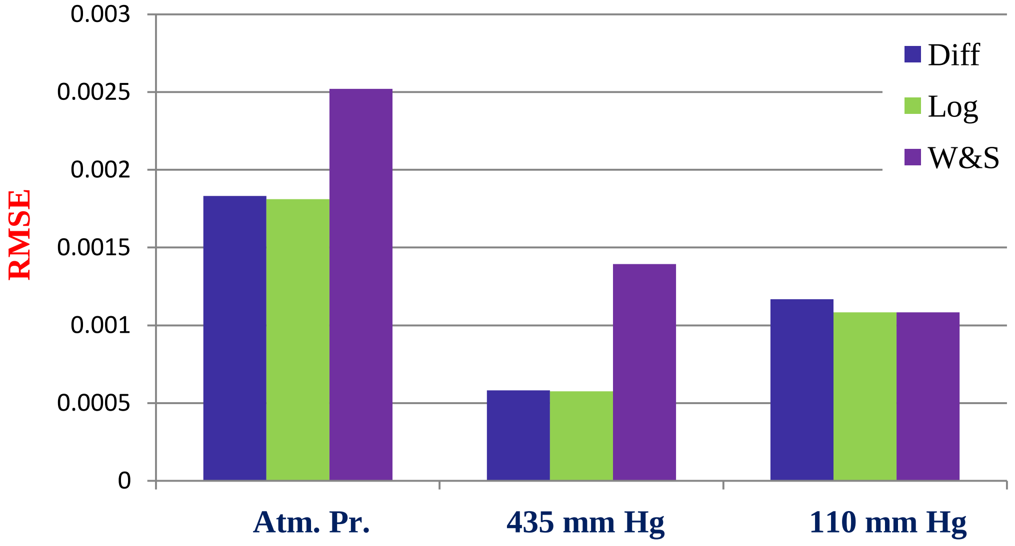


Fig. 4.1.7: Root mean square error for data fit using selected models

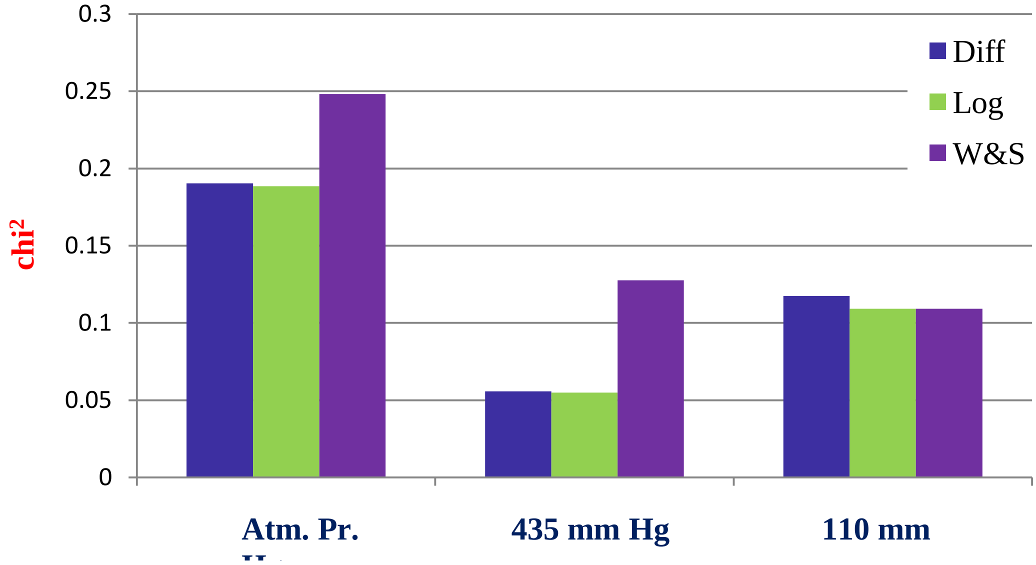


Fig. 4.1.8:Chi square (χ^2)for data fit using selected models

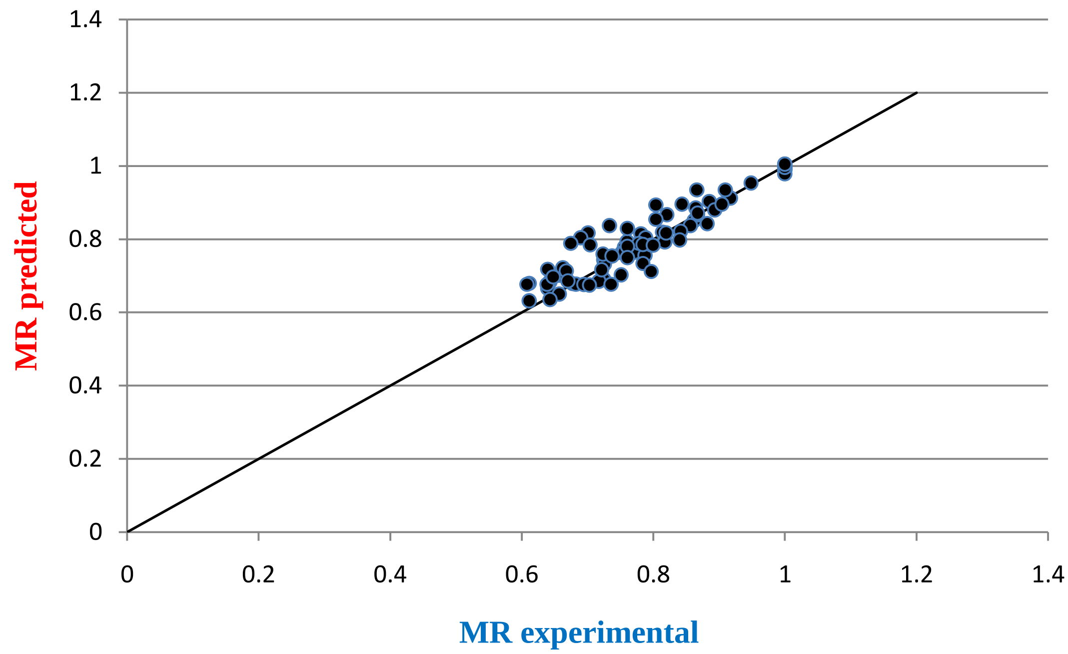


Fig. 4.1.9: Parity chart for observed and predicted moisture ratio using logistic model

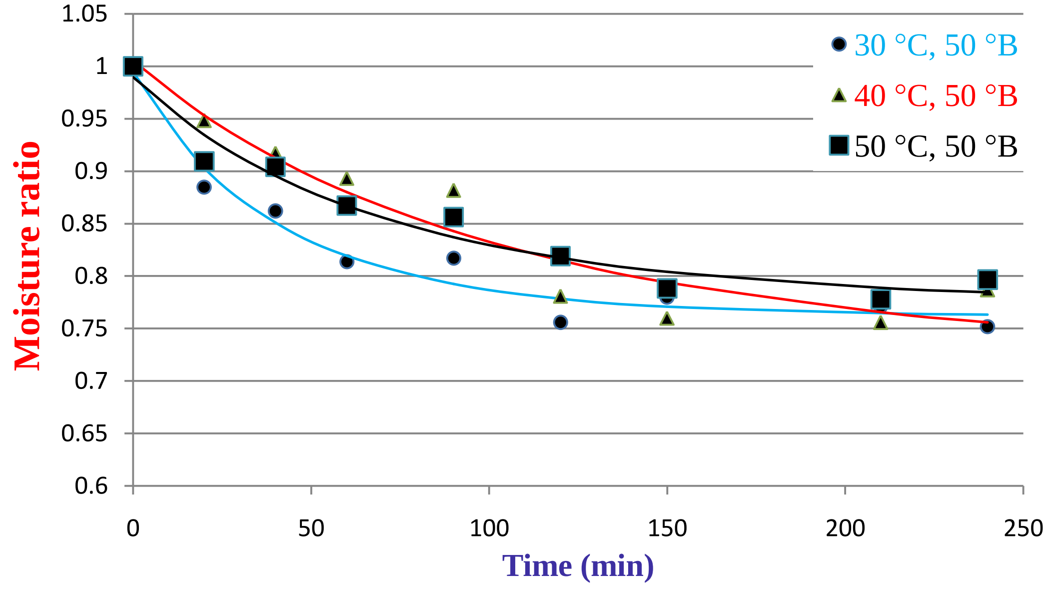


Fig. 4.1.10: Drying kinetics of pineapple cubes in 50 ºB at atmospheric pressure using logistic model.

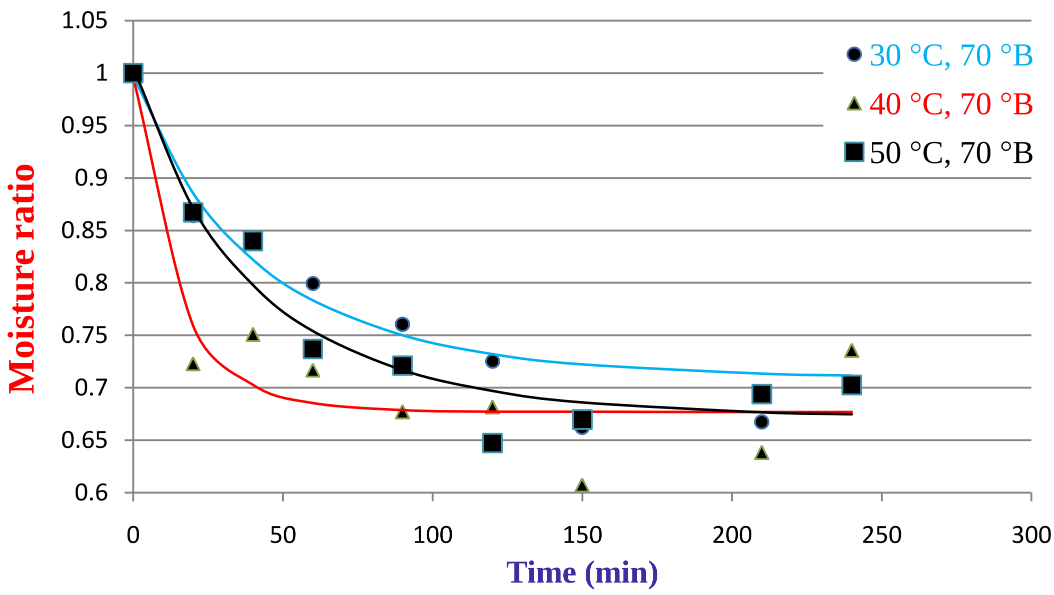


Fig. 4.1.11: Drying kinetics of pineapple cubes in 70 ºB at atmospheric pressure using logistic model.

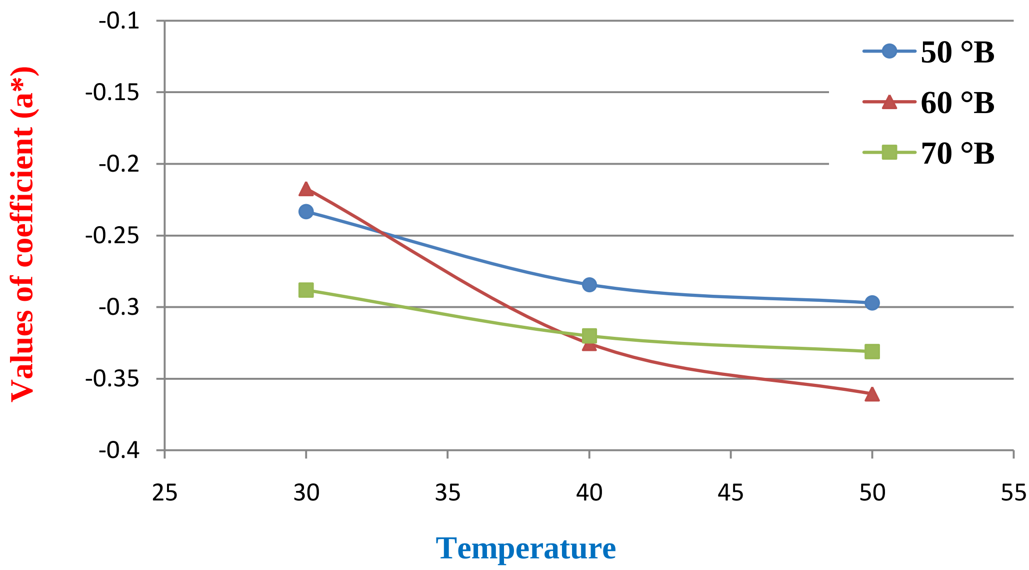


Fig. 4.1.12: Coefficient (a*) obtained from logistic model for drying kinetics at different temperatures (atmospheric pressure).

Table 4.1.2: Coefficients of Logistic model fitted to observations during osmotic dehydration of pineapple cubes at varying pressure levels

Vac	Temp	Brix	A	B	R^2	VE (%)	Loss
760 mm Hg	30	50	-0.2334	0.7620	0.9811	0.9625	0.001903
	40	50	-0.2843	0.7195	0.9593	0.9203	0.005156
	50	50	-0.2973	0.7116	0.9792	0.9588	0.001714
	30	60	-0.2173	0.7746	0.9792	0.9588	0.001714
	40	60	-0.3255	0.6904	0.9817	0.9637	0.003451
	50	60	-0.3607	0.6652	0.9640	0.9293	0.008292
	30	70	-0.2882	0.7095	0.9167	0.8403	0.014177
	40	70	-0.3203	0.6771	0.9265	0.8583	0.014436
	50	70	-0.3312	0.6722	0.9715	0.9439	0.005933
435 mm Hg	30	50	-0.15545	0.841776	0.90498	0.8190	0.004733
	40	50	-0.20274	0.780921	0.96802	0.9371	0.001929
	50	50	-0.14647	0.851161	0.96352	0.9284	0.001514
	30	60	-0.15762	0.841675	0.83201	0.6922	0.009567
	40	60	-0.18735	0.794525	0.84399	0.7123	0.011596
	50	60	-0.14053	0.853527	0.82692	0.6838	0.008058
	30	70	-0.1932	0.806772	0.96251	0.9264	0.002612
	40	70	-0.21186	0.7857	0.96816	0.9373	0.002714
	50	70	-0.20644	0.787757	0.95242	0.9071	0.003865
110 mm Hg	30	50	-0.17833	0.813532	0.88643	0.7858	0.007713
	40	50	-0.21283	0.775406	0.95899	0.9197	0.003466
	50	50	-0.28501	0.75	0.9025	0.8145	0.011747
	30	60	-0.17163	0.795736	0.80367	0.6459	0.020556
	40	60	-0.20525	0.781366	0.87471	0.7651	0.0113
	50	60	-0.24912	0.74234	0.90756	0.8237	0.011704
	30	70	-0.26971	0.715257	0.94245	0.8882	0.007327
	40	70	-0.28713	0.709227	0.92582	0.8571	0.011709
	50	70	-0.31584	0.682799	0.98715	0.9745	0.002307

Similarly the coefficient range of “a*” varied from 0.67 to 0.82 in all the concentrations and temperatures (Fig. 4.14 & 15).

At 110 mm Hg, the coefficient “b*” ranged from 0.68 to 0.81 in the entire range of experimental conditions. As expected, the “b*” value decreased upon increase in temperature of osmosis, since moisture loss was faster at higher temperatures. The coefficient “b*” was much varied at 50 and 60 °B, indicating higher rate of moisture loss up on increase in temperature of solution. However, at 70 °B, the least variation in coefficient “b*” was observed during the entire study (Fig. 4.1.16 & 17).

Comparing the “b*” values at atmospheric pressure as well as the two levels of vacuum pressure 110 mm Hg and 435 mm Hg, lower “b*” values were computed at 110 mm Hg than 435 mm Hg (Fig. 4.1.18). Thus indicating that at higher vacuum level, the moisture removal was higher under same temperature and osmotic potential conditions. In this case it is pertinent to note that coefficient “b*” values were least at atmospheric pressure, at all three degree brix. However, it is important to note that under atmospheric condition alone the osmosed samples were agitated throughout the experimentation, but this was not possible during experimentation at vacuum conditions, owing to instrumental design constraints. Thus the lower values of “b*” at atmospheric condition can be explained to the fact that under agitated condition there was always a better mass transfer since there was always a fresh unsaturated interface at the surface of osmosed particles.

4.2. Evaluation of osmotic pre-treatments and drying methods for dehydrated pineapple slices using response surface methodology (RSM).

Response surface methodology RSM was used to estimate the main effects of osmotic dehydration process on weight reduction WR, water loss WL and solid gain SG in pineapple slices. A 3 level Box-Behnken designwas used (Table 4.2.1) for temperature (30, 40& 50°C), vacuum level (atmospheric pressure 760 mm, 435 & 110 mm Hg), sugar concentration (50, 60 & 70°B). The sample to solution ratio was kept constant 1:4for 180 min.

4.2.1. Weight Reduction (WR)

A vast variation in weight reduction of the samples was observed. The reduction in weight of the samples varied from 7.63% to 13.00% (Table 4. 2. 2). Same way the estimated regression coefficients shows the significant effect of vacuum on WR of

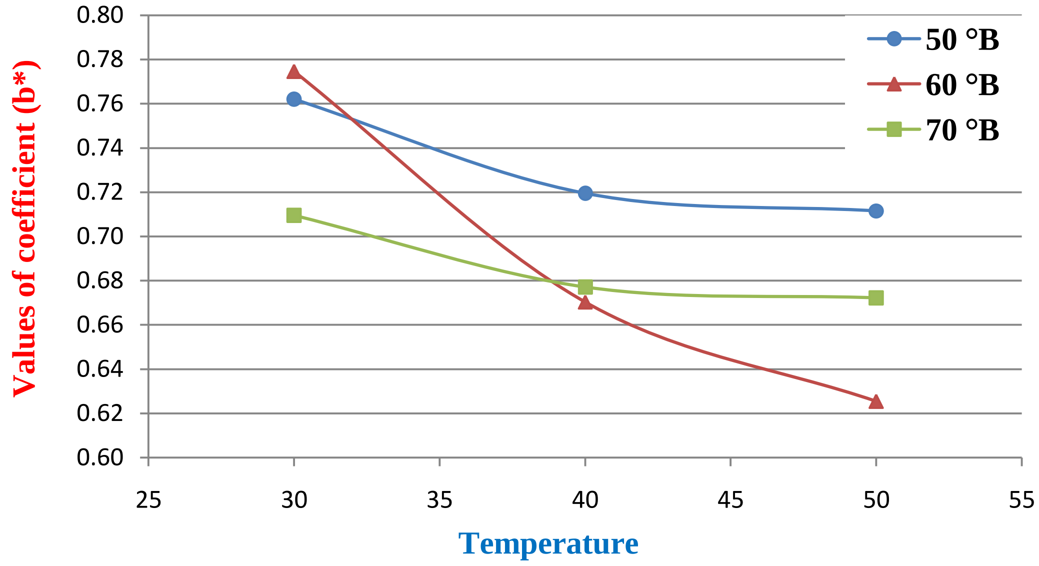


Fig. 4.1.13: Coefficient (b*) obtained from logistic model for drying kinetics at different temperatures (atmospheric pressure).

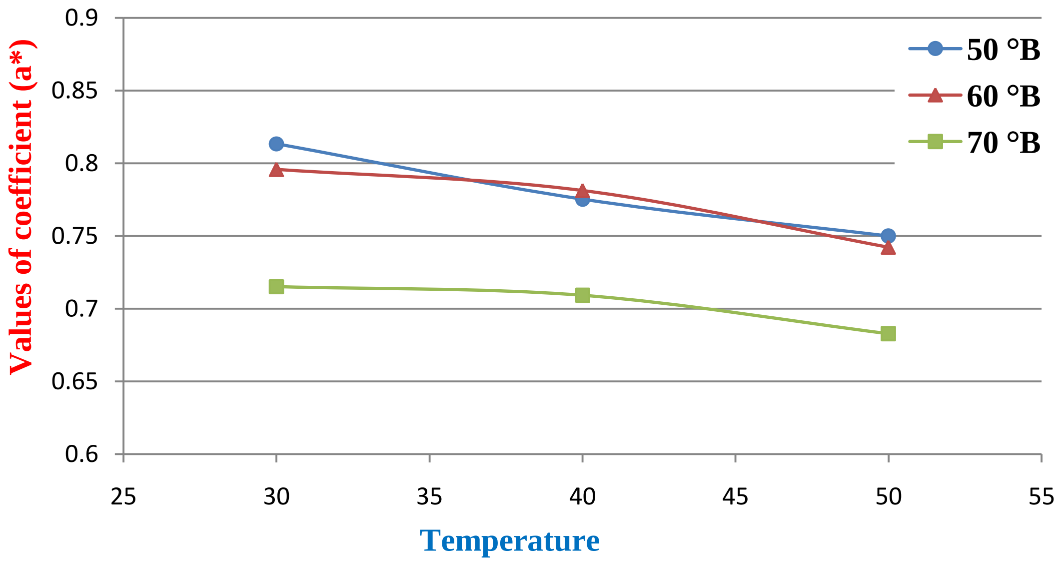


Fig. 4.1.14: Coefficient (a*) obtained from logistic model for drying kinetics at different temperatures (435 mm Hg pressure).

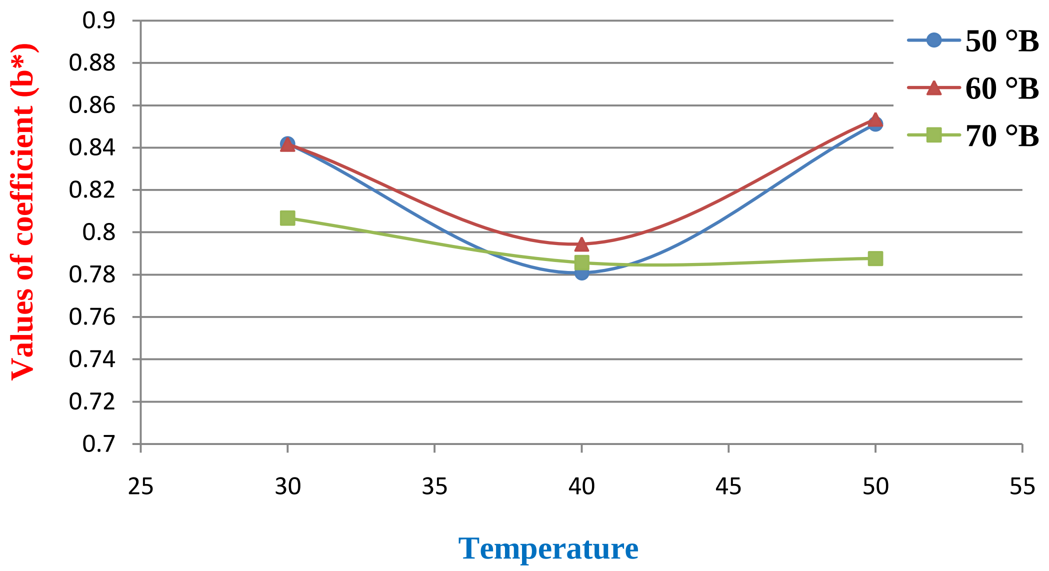


Fig. 4.1.15: Coefficient (b*) obtained from logistic model for drying kinetics at different temperatures (435 mm Hg pressure).

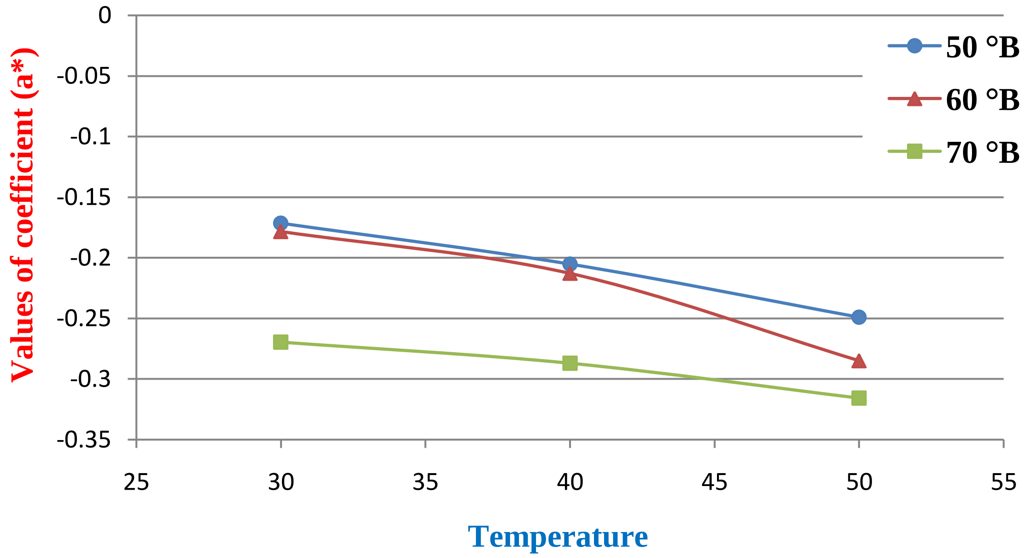


Fig. 4.1.16: Coefficient (a*) obtained from logistic model for drying kinetics at different temperatures (110 mm Hg pressure).

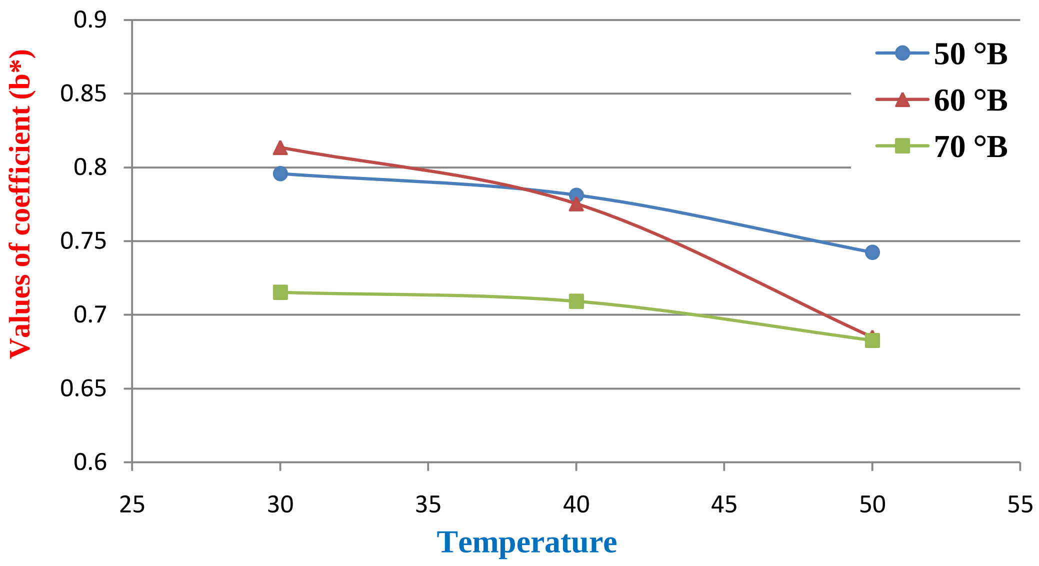


Fig. 4.1.17: Coefficient (b*) obtained from logistic model for drying kinetics at different temperatures (110 mm Hg pressure).

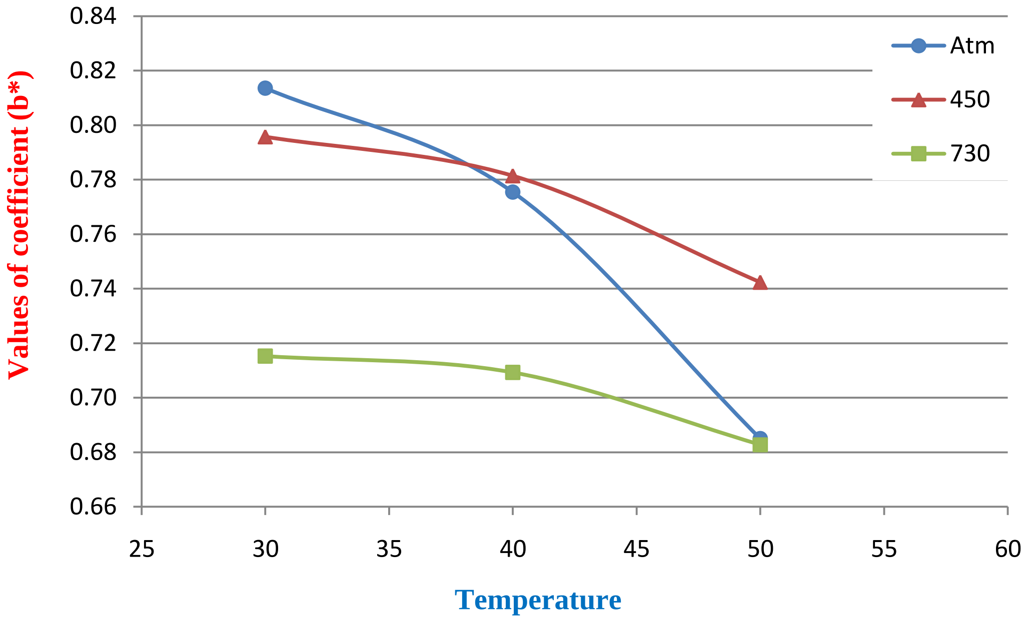


Fig. 4.1.18: Variation in moisture ratio with respect to temperature and levels of vacuum.

slices (p=0.018; Table 4. 2. 3). Similarly °Brix and temperature was also found to affect the WR significantly at (p=0.1).

4.2.2 Solid Gain (SG)

Solid gain of the pineapple slices kept under varying experiment conditions is presented in (Table 4. 2. 2), it can be seen from the table that the solid gain ranged from 0.98% to 3.37%. Estimated regression coefficient for SG shows significant changes Table 4. 2. 4 and it is clearly seen that °Brix having the (p= 0.016) indicates that increase in °Brix has a significant effect on solid gain of pineapple slices.

4.2.3 Water loss (WL)

The percentage of water loss in dehydrated pineapples is presented in Table 4. 2. 2 WL varied from minimum 6.45% to maximum 16.46% in 15 samples. The estimated regression coefficient for WL is presented in (Table 4. 2.5). It was observed from the table that increase in level of vacuum had a significant effect on loss of water (p=0.016; Fig. 4.2.1). Similarly °Brix and temperature were found significant on WL at (p=0.1).

4.2.4 Colour

The total colour difference (ΔE) values recorded for all the 15 samples varying from 69.12 to 81.78 presented in Table 4. 2. 6 clearly shows differences in colour amongst the samples (Fig. 4.2.2). The study of total colour difference applying estimated regression coefficients Table 4. 2. 7 shows that vacuum had a significant effect on colour (p=0.1).

Table 4. 2. 6 reveals that there are some differences in the L* values of dehydrated pineapple slices, the minimum L* value was observed 58.66, whereas 69.95 was the maximum L* value. In case of a* value 1.76 was the lowest and 10.35 was the highest value recorded for a*. Similarly b* value was recorded 43.65 as the highest, while minimum b* (30.25) was observed. The L* value observed from estimated regression coefficients (p= 0.044) for vacuum, (p= 0.001) for °Brix, (p= 0.005) for temperature and (p= 0.014) for vacuum*vacuum which shows the significant effect of parameters on L*. Similarly Brix*Brix and vacuum*Brix found significantly affecting the L* value (p=0.1; Table 4. 2. 8).

4.2.5 Water Activity (A_w)

The data recorded for $A_w$of osmotically dried pineapple slices presented in (Table 4. 2. 6) shows that difference in A_w of the samples was not significant. Variation between the lowest and highest water activity found to be 0.095, whereas the lowest

A_w (0.328) was recorded at 40 °C and 60 °B at 435 mm Hg, and the highest A_w (0.423) was observed at 50 °C and 60 °B at 110 mm Hg.

4.2.6 Ascorbic acid

Ascorbic acid content of pineapple slices is presented in (Table 4. 2. 6). The table shows that content ranged among the different pre-treatments between (38.64 mg/ 100g to highest 52.44 mg/ 100g) of the samples. Similarly ascorbic acid was found to be affected by the parameters while estimated regression coefficients was applied, the all three parameters were found significantly affecting the ascorbic acid value of dehydrated pineapple slices (Table 4. 2. 9).

4.2.7. Organoleptical Evaluation

4.2.7.1 Texture

The data on the organoleptic quality score in respect of texture of dehydrated pineapple slices is presented in Table 4. 2. 10. The overall acceptability recorded minimum 5.2 and maximum 7.8, indicates the ranges between the slightly like and very liking of the product. Similarly the average score 6.1 of texture given by panel shows that they liked the texture of product (Fig. 4.2.3). On the other hand the estimated regression coefficients for the texture of the pineapple samples presented in Table 4. 2. 11 shows significant effect of vacuum on texture score (p= 0.045).

4.2.7.2 Taste

Taste of dehydrated pineapple slices was rated 6.4 by the members of sensory evaluation panel (Table 4. 2. 10). The estimated regression coefficients values Table 4. 2. 12 show that °Brix (p=0.028) followed by temperature* temperature (p= 0.031) which significantly affected the taste of the product (Fig. 4.2.4).

4.2.7.3 Odour

Dehydrated pineapple slices scored 7.31 for its odour by the panel members of sensory evaluation (Table 4. 2. 10), whereas estimated regression coefficients shows (p=0.019) for °Brix*temperature (Table 4. 2. 13), but effect of temperature* temperature and vacuum*temperature found significant at (p=0.1; Fig. 4.2.5).

4.2.10 Appearance

The sensory panel scored 6.38 for the dehydrated pineapple slices for its appearance (Table 4. 2. 10).Further study of estimated regression coefficients, Table 4.2. 14 demonstrated vacuum (p=0.003), °Brix (p=0.025, vacuum*vacuum (p=0.037),

Table 4. 2. 1: Independent Variables and Levels used for osmotic dehydration

Variables	**Coded variable level**			
	Symbols	-1	0	1
Vacuum level (mm Hg)	X1	110	435	Room (760)
Sugar concentration (ºB)	X2	50	60	70
Osmotic temperature (ºC)	X3	30	40	50

Table 4. 2. 2: Response Surface Design

Design	**Coded values**			**Actual values**		
	X1	**X2**	**X3**	**WR (%)**	**WL (%)**	**SG (%)**
1	1	0	-1	13.46	11.53	1.93
2	1	0	1	14.80	11.98	1.82
3	0	1	-1	12.98	10.68	1.81
4	0	-1	1	12.77	9.08	1.09
5	0	0	0	11.59	9.62	1.76
6	-1	0	1	12.33	9.23	2.09
7	0	0	0	9.64	8.98	1.66
8	1	1	0	12.58	10.63	1.95
9	1	-1	0	9.53	9.73	1.20
10	0	1	1	13.00	16.46	3.04
11	-1	0	-1	7.63	7.56	1.07
12	0	0	0	9.62	9.86	2.06
13	0	-1	-1	7.78	5.60	0.98
14	-1	-1	0	8.94	6.45	2.50
15	-1	1	0	11.63	8.26	3.37

WR: Weight Reduction

WL: Water Loss

SG: Solid Gain

Table 4. 2. 6: Colour, Water activity and Ascorbic acid content of dried pineapple slices

Design	Coded values			Colour			
	X1	X2	X3	L*	a*	b*	Total Colour (Chroma)
1	-1	0	-1	68.82	6.8	43.65	81.779
2	-1	0	1	63.45	6.95	40.47	75.578
3	0	1	-1	69.95	4.76	38.4	79.939
4	0	-1	1	61.53	5.26	39.21	73.151
5	0	0	0	65.32	3.45	32.3	72.951
6	1	0	1	61.27	2.35	32.26	69.284
7	0	0	0	67.20	2.43	34.92	75.770
8	-1	1	0	64.39	7.32	36.26	74.259
9	-1	-1	0	62.11	2.13	30.25	69.118
10	0	1	1	65.66	1.76	35.67	74.744
11	1	0	-1	64.11	7.35	42.05	77.022
12	0	0	0	66.45	2.23	36.22	75.713
13	0	-1	-1	63.73	6.12	39.88	75.428
14	1	-1	0	58.66	4.46	40.11	71.202
15	1	1	0	66.46	10.35	40.25	78.384

Table 4. 2. 6-b: Water activity and Ascorbic acid content of dried pineapple slices

Design	Coded values				
	X1	X2	X3	A_w	Ascorbic Acid
1	-1	0	-1	0.345	49.68
2	-1	0	1	0.387	41.40
3	0	1	-1	0.419	52.44
4	0	-1	1	0.398	41.40
5	0	0	0	0.377	44.16
6	1	0	1	0.423	41.40
7	0	0	0	0.413	41.40
8	-1	1	0	0.378	44.16
9	-1	-1	0	0.388	49.68
10	0	1	1	0.411	47.62
11	1	0	-1	0.365	38.64
12	0	0	0	0.328	44.16
13	0	-1	-1	0.335	52.44
14	1	-1	0	0.422	38.64
15	1	1	0	0.384	49.68

Table 4.2.3: Estimated Regression Coefficients for WR

Term	Coef	StDev	T	p
Constant	10.283	1.4570	7.058	0.001
Vacuum	-3.105	0.8922	-3.480	**0.018**
Brix	2.271	0.8922	2.546	**0.052**
Temp	1.881	0.8922	2.109	**0.089**
Vacuum*Vacuum	-0.095	1.3133	-0.073	0.945
Brix*Brix	1.982	1.3133	1.509	0.192
Temp*Temp	0.617	1.3133	0.470	0.658
Vacuum*Brix	0.410	1.2618	0.325	0.758
Vacuum*Temp	-0.410	1.2618	-0.325	0.758
Brix*Temp	1.008	1.2618	0.798	0.461

Table 4.2.4: Estimated Regression Coefficients for SG

Term	Coef	StDev	T	p
Constant	2.1267	0.2304	9.232	0.000
Vacuum	0.1912	0.1411	1.356	0.233
Brix	0.5000	0.1411	3.544	**0.016**
Temp	0.0812	0.1411	0.576	0.590
Vacuum*Vacuum	0.0379	0.2076	0.183	0.862
Brix*Brix	0.4904	0.2076	2.362	**0.065**
Temp*Temp	-0.1871	0.2076	-0.901	0.409
Vacuum*Brix	-0.0700	0.1995	-0.351	0.740
Vacuum*Temp	0.0325	0.1995	0.163	0.877
Brix*Temp	0.4300	0.1995	2.155	0.084

Table 4.2.5: Estimated Regression Coefficients for WL

Term	Coef	StDev	T	p
Constant	8.153	1.4312	5.697	0.002
Vacuum	-3.296	0.8764	-3.761	**0.013**
Brix	1.771	0.8764	2.021	**0.099**
Temp	1.798	0.8764	2.051	**0.096**
Vacuum*Vacuum	-0.133	1.2901	-0.103	0.922
Brix*Brix	1.497	1.2901	1.160	0.298
Temp*Temp	0.805	1.2901	0.624	0.560
Vacuum*Brix	0.477	1.2395	0.385	0.716
Vacuum*Temp	-0.445	1.2395	-0.359	0.734
Brix*Temp	0.575	1.2395	0.464	0.662

Table 4.2.7: Estimated Regression Coefficients for Total Colour

Term	Coef	StDev	T	p
Constant	5.8900	0.6713	8.774	0.000
Vacuum	-0.9588	0.4111	-2.332	**0.067**
Brix	-0.1663	0.4111	-0.404	0.703
Temp	0.2075	0.4111	0.505	0.635
Vacuum*Vacuum	-0.5713	0.6051	-0.944	0.388
Brix*Brix	0.0138	0.6051	0.023	0.983
Temp*Temp	0.9313	0.6051	1.539	0.184
Vacuum*Brix	-0.1675	0.5813	-0.288	0.785
Vacuum*Temp	-0.2500	0.5813	-0.430	0.685
Brix*Temp	-0.8350	0.5813	-1.436	0.210

temperature*temperature (p=0.001) and °Brix*temperature (p=0.000) were found highly significant for appearance of the dehydrated pineapple slices (Fig. 4.2.6).

Considering the results from all 15 runs the treatment (50 °C, 70 °B under 435 mm Hg vacuum) was found most acceptable based on three levels of vacuum 760, 435 and 110 mm Hg applied for osmotic dehydration of pineapple slices as it exhibited better solid gain, texture, higher ascorbic acid as well as overall acceptability of the finished product.

4.3. Packaging and storage conditions for osmotically dehydrated pineapple slices.

4.3.1. Moisture content

The moisture content of dehydrated pineapple slices increased significantly with the increase in days of storage (Table 4.3.1). The moisture content increased from (5.22 % to 6.73%) during the storage when the samples were packed in normal package and stored at room temperature. The gain of moisture was low during the storage in the samples packed in vacuum and stored at low temperature. However, the moisture content increased faster and it was higher in the sample packed in normal packaging material and stored at room temperature. The moisture content increased from its initial value (5.22%) to 6.73% at room temperature and 5.64% at low temperature during four month of storage when the samples were packed in normal packaging material and similarly moisture content increased to 5.99% at room temperature and 5.49% at low temperature when the samples were packed under vacuum.

It is evident from the Table 4.3.1 that temperature and period of storage greatly influenced the moisture content of dehydrated pineapple slices. The moisture content was higher at room temperature as compared to low temperature. Thus, the moisture content of the pineapple slices was statistically significant. Storage temperature and mode of pack both affect the moisture content of the pineapple slices and differences were statistically significantamongst them.

The result of comparison of mean values shows that both storage temperature and vacuum packaging affected the moisture content significantly in osmotically dehydrated pineapple slices during storage period. The mean of moisture content (6.10%) of normally packed dehydrated product stored at room temperature observed and it highly varies from other three packages stored at low and room temperature.

4.3.2 Ascorbic acid

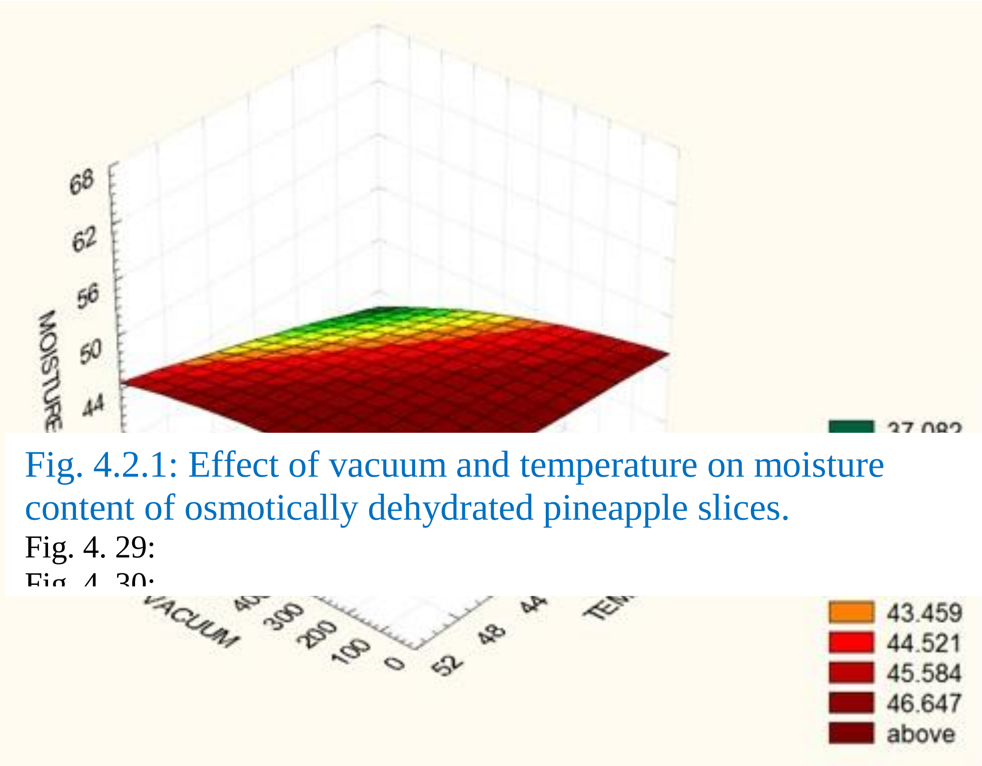


Fig. 4.2.1: Effect of vacuum and temperature on moisture content of osmotically dehydrated pineapple slices.

Fig. 4. 29:

Fig. 4. 30:

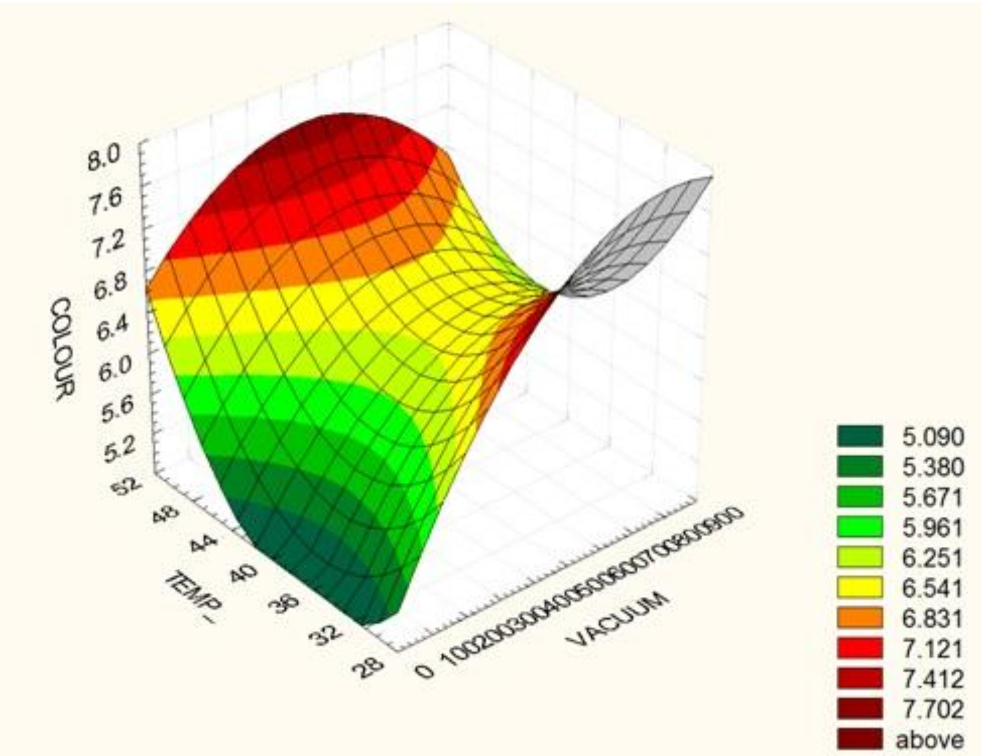


Fig. 4.2.2: Effect of vacuum and temperature on colour of osmotically dehydrated pineapple slices.

Fig. 4. 29:

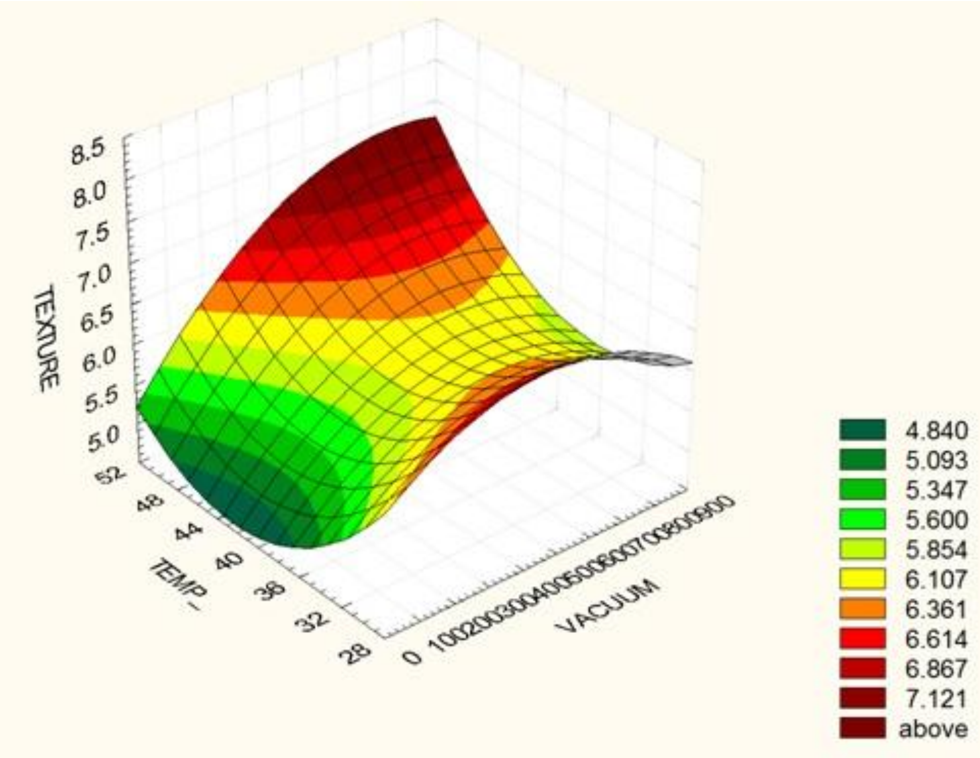


Fig. 4.2.3: Effect of vacuum and temperature on texture of osmotically dehydrated pineapple slices.

Fig. 4. 29:

Fig. 4. 30:

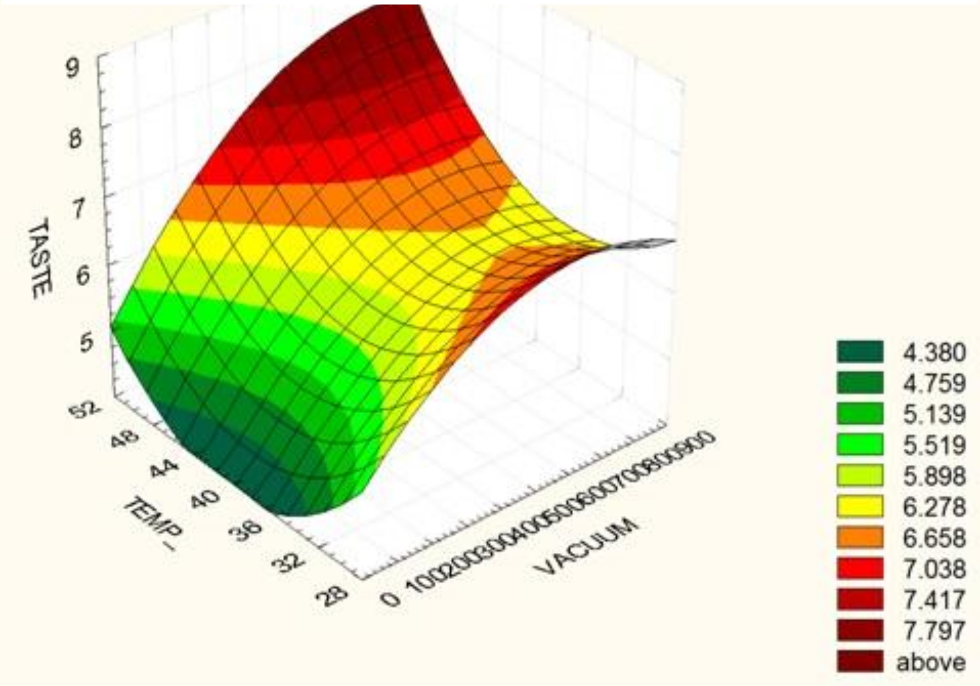


Fig. 4.2.4: Effect of vacuum and temperature on taste of osmotically dehydrated pineapple slices.

Fig. 4. 29:

Fig. 4. 30:

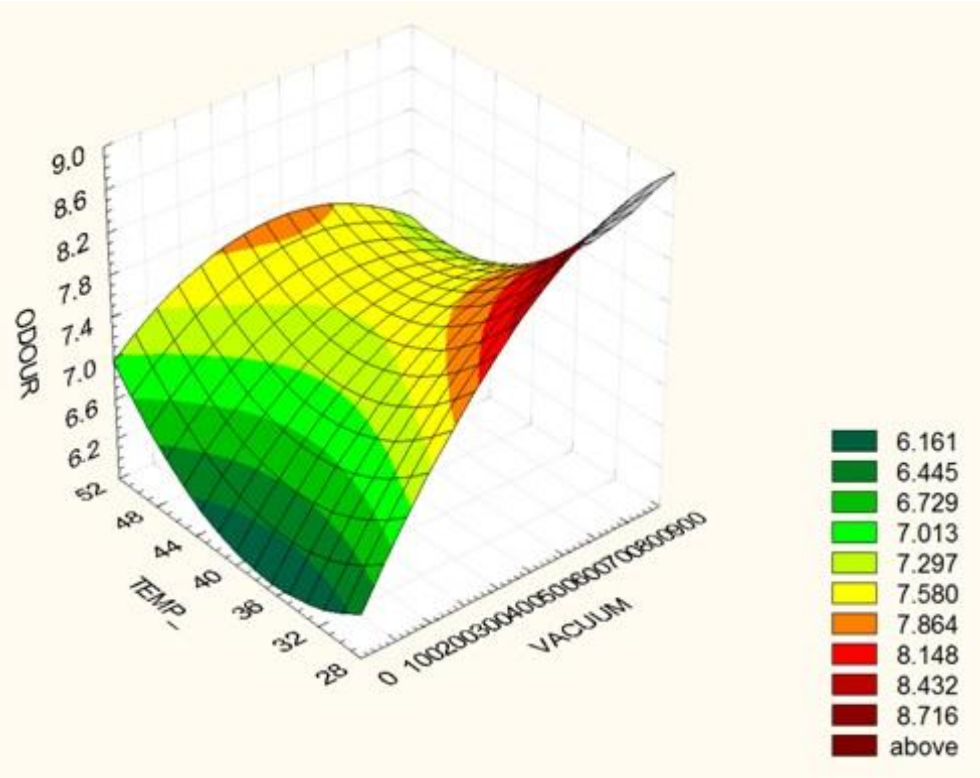


Fig. 4.2.5: Effect of vacuum and temperature on odour of osmotically dehydrated pineapple slices.

Fig. 4. 29:

Fig. 4. 30:

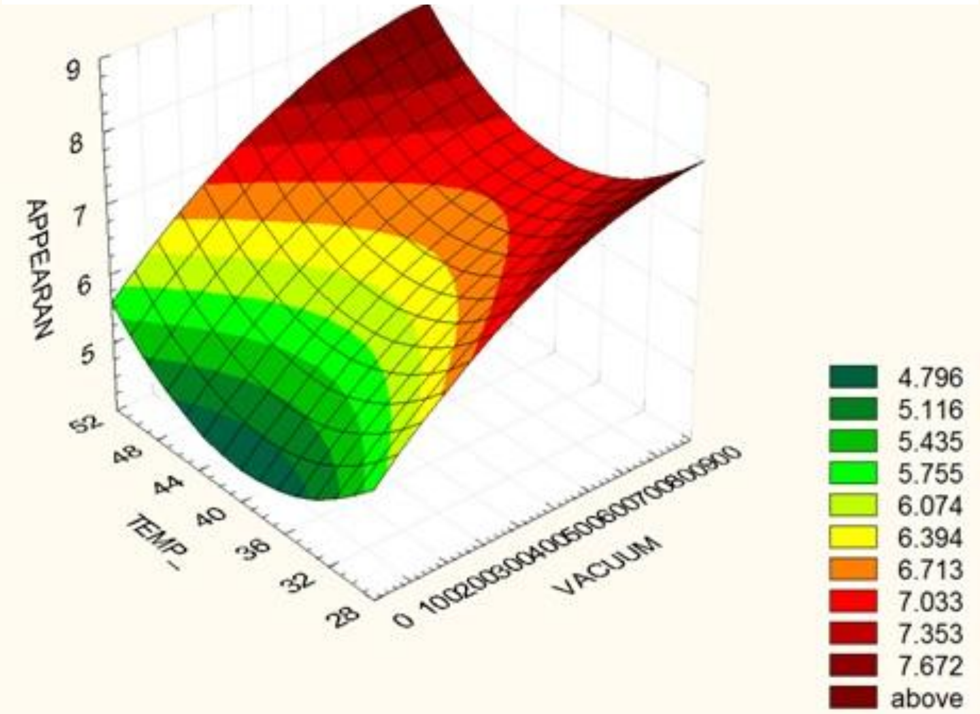


Fig. 4.2.6: Effect of vacuum and temperature on appearance of osmotically dehydrated pineapple slices.

Fig. 4. 29:

Fig. 4. 30:

e of organoleptical values

d values		Sensory values				
X2	X3	Appearance	Texture	Taste	Odour	Colour
0	-1	7.67	7.00	7.67	8.67	6.67
0	1	8.33	7.33	7.00	7.33	8.33
1	-1	7.67	7.00	7.67	8.33	7.67
-1	1	7.33	8.00	7.67	8.33	7.67
0	0	5.33	6.33	7.00	7.67	5.33
0	1	6.00	5.33	6.33	7.00	5.33
0	0	8.00	7.33	6.33	7.33	7.67
1	0	6.67	5.33	6.00	8.00	6.00
-1	0	6.00	6.00	6.33	7.00	6.00
1	1	5.33	5.00	6.67	6.67	5.67
0	-1	5.33	5.33	5.33	6.67	4.67
0	0	6.00	4.67	5.33	7.00	4.67
-1	-1	6.33	6.00	6.33	7.33	6.33
-1	0	5.00	5.00	5.33	6.00	5.00
1	0	4.67	5.67	5.00	6.33	4.33

Table 4.2.8: Estimated Regression Coefficients for L* Value

Term	Coef	StDev	T	p
Constant	66.323	0.6306	105.172	0.000
Vacuum	-1.034	0.3862	-2.677	**0.044**
Brix	2.554	0.3862	6.613	**0.001**
Temp	-1.837	0.3862	-4.758	**0.005**
Vacuum*Vacuum	-2.112	0.5684	-3.715	**0.014**
Brix*Brix	-1.307	0.5684	-2.299	**0.070**
Temp*Temp	0.201	0.5684	0.353	0.738
Vacuum*Brix	1.380	0.5461	2.527	**0.053**
Vacuum*Temp	0.632	0.5461	1.158	0.299
Brix*Temp	-0.523	0.5461	-0.957	0.383

Table 4.2.9: Estimated Regression Coefficients for Ascorbic acid

Term	Coef	StDev	T	p
Constant	43.240	1.1078	39.031	0.000
Vacuum	-2.070	0.6784	-3.051	**0.028**
Brix	1.725	0.6784	2.543	**0.052**
Temp	-2.415	0.6784	-3.560	**0.016**
Vacuum*Vacuum	-1.955	0.9986	-1.958	0.108
Brix*Brix	4.255	0.9986	4.261	**0.008**
Temp*Temp	1.495	0.9986	1.497	0.195
Vacuum*Brix	4.140	0.9594	4.315	**0.008**
Vacuum*Temp	2.760	0.9594	2.877	**0.035**
Brix*Temp	2.070	0.9594	2.158	**0.083**

Table 4.2.11: Estimated Regression Coefficients for Texture

Term	**Coef**	**StDev**	**T**	**p**
Constant	6.4433	0.5901	10.918	0.000
Vacuum	-0.9587	0.3614	-2.653	**0.045**
Brix	-0.0400	0.3614	-0.111	0.916
Temp	-0.0013	0.3614	-0.003	0.997
Vacuum*Vacuum	-0.3454	0.5319	-0.649	0.545
Brix*Brix	-0.5129	0.5319	-0.964	0.379
Temp*Temp	0.7346	0.5319	1.381	0.226
Vacuum*Brix	-0.2500	0.5111	-0.489	0.645
Vacuum*Temp	0.0025	0.5111	0.005	0.996
Brix*Temp	-0.8350	0.5111	-1.634	0.163

Table 4.2.12: Estimated Regression Coefficients for Taste

Term	**Coef**	**StDev**	**T**	**p**
Constant	6.2200	0.3332	18.669	0.000
Vacuum	-0.6262	0.2040	-3.069	**0.028**
Brix	-0.0400	0.2040	-0.196	0.852
Temp	0.0837	0.2040	0.410	0.698
Vacuum*Vacuum	-0.5288	0.3003	-1.761	0.139
Brix*Brix	-0.0263	0.3003	-0.087	0.934
Temp*Temp	0.8912	0.3003	2.968	**0.031**
Vacuum*Brix	-0.0000	0.2885	-0.000	1.000
Vacuum*Temp	0.4175	0.2885	1.447	0.208
Brix*Temp	-0.5850	0.2885	-2.027	**0.098**

Table 4.2.13: Estimated Regression Coefficients for Odour

Term	Coef	StDev	T	p
Constant	7.3333	0.2235	32.812	0.000
Vacuum	-0.6250	0.1369	-4.567	**0.006**
Brix	0.0837	0.1369	0.612	0.567
Temp	-0.2088	0.1369	-1.525	0.188
Vacuum*Vacuum	-0.3742	0.2015	-1.857	0.122
Brix*Brix	-0.1267	0.2015	-0.629	0.557
Temp*Temp	0.4583	0.2015	2.275	**0.072**
Vacuum*Brix	-0.1675	0.1936	-0.865	0.426
Vacuum*Temp	0.4175	0.1936	2.157	**0.083**
Brix*Temp	-0.6650	0.1936	-3.436	**0.019**

Table 4.2.14: Estimated Regression Coefficients for Appearance

Term	Coef	StDev	T	p
Constant	5.727	0.14160	40.444	0.000
Vacuum	-0.451	0.08671	-5.204	**0.003**
Brix	-0.274	0.08671	-3.157	**0.025**
Temp	0.105	0.08671	1.211	0.280
Vacuum*Vacuum	-0.361	0.12763	-2.827	**0.037**
Brix*Brix	-0.021	0.12763	-0.163	0.877
Temp*Temp	0.812	0.12763	6.359	**0.001**
Vacuum*Brix	0.180	0.12263	1.468	0.202
Vacuum*Temp	-0.073	0.12263	-0.591	0.580
Brix*Temp	-1.048	0.12263	-8.542	**0.000**

Ascorbic acid decreased with increase in storage period (Table 4.3.2). The reduction in ascorbic acid was more in the samples packed in normal packaging material and

stored at room temperature as compared to samples packed under vacuum and stored at low temperature. The ascorbic acid decreased from the initial value (47.62 mg/ 100g) to 24.42 mg/100g at room temperature and packed under normal condition.
However, the retention of ascorbic acid was more in samples packed under vacuum and stored at low temperature. The ascorbic acid degradation was very fast at higher temperature as compared to low temperature. However, the effect of vacuum was found insignificant for ascorbic acid retention of osmotically dehydrated pineapple slices during storage.

4.3.3 Total sugar

Total sugar content of the dried pineapple slices recorded during 4 month of storage presented in Table 4.3.3 shows that with the increase in time of storage Total sugar content increased continuously in all the samples. The initial amount of sugars in osmotically dehydrated pineapple slices was recorded 51.03 % before packaging and increased continuously till end of 4 month of storage. Increase in total sugar was more in the sample when packed as normal pack and stored at room temperature 60.04% as compared to samples packed with vacuum and stored at room temperature (55.62%), similarly normally packed samples stored at low temperature 54.71% and vacuum packed samples 54.42% stored at low temperature. The effect of vacuum and storage temperature on total sugar content of osmotically dehydrated pineapple slices shows that both temperature and vacuum affect the total sugar significantly of dried pineapple slices during storage.

4.3.4. Total phenolics

The total phenolics content of dehydrated pineapple during 4 month of storage decreased rapidly with increase in storage interval (Table 4.3.4). Slices packed in vacuum pouches and stored at low temperature retain the maximum quantity of (16.54 mg GAE/100g) while the initial amount was (86.38 mg GAE/100g) at time of packaging. The maximum loss was recorded in normal packed slices and stored at room temperature and decreased from (86.38 to 7.55 mg GAE/100g) in NPRT to vacuum packed stored at room temperature (9.20 mg GAE/100g) and normally packed slices stored at low temperature (12.54 mg GAE/100g). The variation in total phenolics content of osmotically dehydrated pineapple slices showed a significant difference in all four conditions of storage, in both vacuum and normally packed

Table 4.3.1: Changes in moisture content (%) of osmotically dehydrated pineapple slices during storage.

Initial moisture (5.22%)

Packages	Days of Storage				
	30	**60**	**90**	**120**	**Mean**
NPRT	5.80	6.20	6.46	6.73	6.30
NPLT	5.31	5.45	5.46	5.64	5.47
VPRT	5.27	5.59	5.93	5.99	5.70
VPLT	5.26	5.29	5.36	5.49	5.35
Mean	5.41	5.63	5.80	5.96	

	Storage Period (S)	Treatment(T)	S x T
C.D (0.5)	0.145	0.130	0.290

Table 4.3.2: Changes in ascorbic acid (mg/100g) of osmotically dehydrated pineapple slices during storage.

Initial ascorbic acid (47.62 mg/100g)

Packages	Days of Storage				
	30	**60**	**90**	**120**	**Mean**
NPRT	35.72	31.91	27.08	24.42	29.78
NPLT	47.29	46.81	45.13	44.4	45.91
VPRT	38.1	36.1	31.91	28.86	33.74
VPLT	47.29	46.54	45.13	44.4	45.84
Mean	42.1	40.34	37.3125	35.52	

	Storage Period (S)	Treatment(T)	S x T
C.D(0.05)	0.695	0.621	1.389

Table 4.3.3: Changes in total sugar content (%) of osmotically dehydrated pineapple slices during storage.

Initial sugar content (51.03%)

Packages	**Days of Storage**				
	30	**60**	**90**	**120**	**Mean**
NPRT	53.43	54.98	57.18	60.04	56.41
NPLT	52.23	53.37	53.90	54.71	53.55
VPRT	52.40	53.68	54.53	55.62	54.06
VPLT	51.77	52.83	53.36	54.42	53.10
Mean	52.46	53.71	54.74	56.20	

	Storage Period (S)	Treatment(T)	S x T
C.D(0.05)	0.381	0.381	0.763

Table 4.3.4: Changes in phenolics content [mg (GAE)/100g] of osmotically dehydrated pineapple slices during storage.

Initial phenolics [86.38mg GAE/100g]

Packages	**Days of Storage**				
	30	**60**	**90**	**120**	**Mean**
NPRT	53.57	38.66	16.31	7.55	29.02
NPLT	65.86	40.61	26.88	12.35	36.43
VPRT	70.82	34.92	24.35	9.20	34.82
VPLT	77.13	54.11	35.37	16.54	45.79
Mean	66.85	42.08	25.73	11.41	

	Storage Period (S)	Treatment(T)	S x T
C.D(0.05)	0.23	0.21	0.47

samples during storage. The trend of phenolics reduction was slower for the first and second month in vacuum packed samples stored at low temperature, which must be due to combination of both vacuum and low temperature storage condition. However the phenolics content was affected significantly during storage.

4.3.5. Total carotenoids

The total carotenoids content of fresh pineapple fruits was found (0.432 ±0.015 mg/100g), however in dehydrated pineapple slices total carotenoids content could not be detected due to very low amount of total carotenoids present. Similar reports by other researchers have also reported.

4.3.6. Water Activity

The changes in water activity $A_w$of osmotically dehydrated pineapple slices presented in Table 4.3.5. There was a great increase $A_w$with theincrease in days of storage. The initial water activity 0.44 increased to 0.56 when samples were normally packed and stored at room temperature, meanwhile the slices packed under vacuum and stored at low temperature had very less increase to(0.45)in $A_{w.}$It can be seen from the table that both storage temperature and vacuum packaging affect the$A_w$behaviour of osmotically dehydrated pineapple slices during storage.

The comparison of the mean values of the individuals shows that the A_w is also affected by storingthe samples at low temperature but the difference in $A_w$was found more at room temperature followedby sample packed under the normal conditions.

4.3.7. Hardness

The hardness of the dehydrated pineapple slices as measured using Texture analyser decreased with increase in storage period at both the storage temperature and mode of packaging. The hardness in pineapple slices during storage was less in the sample packed in normal packs and stored at room temperature. Hardness was higher in the sample packed in vacuum and stored at room temperature. However, those stored at low temperature retain slightly lower hardness as compared to room temperature stored samples. Application of vacuum created a sudden toughness to the vacuum packed samples and the maximum hardness was recorded in vacuum packed samples stored at low temperature after one month (882.14 g) which decreased (608.68 g) after 4 month of storage. Duration of storage and mode of packaging were found statistically significant on decrease of hardness in osmotically dehydrated pineapple slices (Table 4.3.6).

4.3.8 Total colour difference

Significant changes in Total colour difference(ΔE) wasrecorded during storage of osmotically dehydrated pineapple slice (Table 4.3.7). Total colour of pineapple slices decreased with the increase in time of storage. Maximum decrease in colour at the end of the storage was found under normally packed samples and stored at room temperature and minimum decrease was recorded in vacuum packed and stored at low temperature followed by sample packed in normal package and stored at low temperature. However the differences between the normal and vacuum packed slices were very less when the samples were stored at low temperature. The study of storage temperature and vacuum packed samples shows that storage temperature affected the total colour changes significantly of dehydrated pineapple slices.

4.3.9. Organoleptic evaluation

4.3.9.1. Colour

Storage temperature affected colour of the pineapple slices significantly during storage, the colour of the product was decreased with increase in time of storage Table. 4.3.8 and the product stored at low temperature was scored much better than the products stored at room temperature. Vacuum packed slices stored at low temperature was scored highest 9 in sensory of colour after four months.

4.3.9.2 Appearance

The appearance of dehydrated pineapple slices were decreased with increase in storage time (Table 4.3.8). The maximum score was recorded 8.5 in normally packed dried pineapple slices and stored at low temperature, while the sample packed with vacuum and stored at room temperature retained poor appearance after four months of storage.

4.3.9.3. Texture

The score for texture of dehydrated pineapple slices was maximum 8 in normally packed sample and stored at low temperature followed by the dried pineapple slices packed normally and stored at room temperature (Table 4.3.8), whereas the vacuum packed samples scored very low sensory score from the beginning of the storage to end of the storage.

4.3.9.4. Taste

Taste of the dried pineapple slices was highly acceptable compere to other sensory attributes during storage period. The score of the sense of taste was 8 in normally packed slices stored at low temperature (Table 4.3.8).

Table 4.3.5: Changes in water activity (Aw) of osmotically dehydrated pineapple slices during storage.

Initial A_w (0.44)

Packages	Days of Storage				
	30	60	90	120	Mean
NPRT	0.45	0.46	0.52	0.56	0.50
NPLT	0.45	0.45	0.50	0.52	0.48
VPRT	0.44	0.45	0.45	0.45	0.45
VPLT	0.44	0.45	0.45	0.45	0.45
Mean	0.45	0.45	0.48	0.50	

	Storage Period (S)	Treatment(T)	S x T
C.D(0.05)	0.011	0.010	0.023

Table 4.3.6: Changes in hardness (gram) of osmotically dehydrated pineapple slices during storage.

Initial hardness (167.80gram)

Packages	Days of Storage				
	30	60	90	120	Mean
NPRT	165.70	157.41	145.81	130.90	149.95
NPLT	168.31	153.65	163.21	161.12	161.57
VPRT	814.57	801.43	790.20	750.42	789.16
VPLT	882.02	869.61	865.95	949.55	891.78
Mean	507.65	495.52	491.29	498.00	

	Storage Period (S)	Treatment(T)	S x T
C.D(0.05)	4.57	4.57	9.137

Table 4.3.7: Changes in total colour (ΔE) of osmotically dehydrated pineapple slices during storage.

Initial colour (78.94*)

Packages	**Days of Storage**				
	30	**60**	**90**	**120**	**Mean**
NPRT	75.48	70.30	66.46	62.33	68.64
NPLT	76.20	75.59	73.55	**71.59**	74.23
VPRT	77.38	73.53	67.19	64.60	70.68
VPLT	77.60	76.82	74.24	**73.50**	75.54
Mean	76.67	74.06	70.36	68.01	

	Storage Period (S)	Treatment(T)	S x T
C.D(0.05)	0.775	0.693	0.549

Table 4.3.8 Sensory score of osmotically dehydrated pineapple slices during storage.

Days of Storage	Mode of packaging	Colour	Apperance	Texture	Taste	Odour	Over all
0	NPRT	9.00	9.00	8.00	8.00	9.00	8.60
	NPLT	9.00	9.00	8.00	8.00	9.00	8.60
	VPRT	9.00	9.00	8.00	8.00	9.00	8.60
	VPLT	9.00	9.00	8.00	8.00	9.00	8.60
30	NPRT	9.00	8.50	7.50	7.70	8.50	8.24
	NPLT	9.00	9.00	8.00	8.00	9.00	8.60
	VPRT	8.50	8.50	7.50	7.50	8.50	8.10
	VPLT	9.00	9.00	7.80	8.00	9.00	8.56
60	NPRT	8.80	8.00	7.00	7.60	7.00	7.68
	NPLT	9.00	8.50	8.00	7.60	9.00	8.42
	VPRT	8.50	7.70	7.00	6.00	7.00	7.24
	VPLT	9.00	9.00	7.00	7.00	9.00	8.20
90	NPRT	7.00	7.00	7.00	6.60	6.00	6.72
	NPLT	9.00	8.50	8.50	8.00	9.00	8.60
	VPRT	7.00	6.00	5.00	6.00	6.00	6.00
	VPLT	9.00	8.80	5.00	7.00	9.00	7.76
120	NPRT	3.00	6.00	6.50	6.00	5.00	5.30
	NPLT	8.50	8.00	8.50	8.00	9.00	8.40
	VPRT	4.00	5.00	4.00	3.00	4.00	4.00
	VPLT	9.00	7.00	4.00	7.00	8.00	7.00

4.3.9.5. Odour

Like all other sensory attributes odour of the dehydrated pineapple slices was also affected significantly (Table 4.3.8). The vacuum packed dried pineapple slices stored at low temperature scored the highest sensory since after four month of storage, whereas samples stored at room temperature scored very low score for retention of odour.

4.3.9.6. Overall acceptability

Normal packed samples stored at low temperature scored the highest overall acceptability score after four month of storage (Table 4.3.8). The initial score 8.6 for overall acceptability slightly decreased to 8.4 in normally packed dried pineapples stored at low temperature, but the minimum acceptability score was recorded in vacuum packed dehydrated pineapple slices and stored at room temperature (Plate 9 & 10).

4.3.10. Microbial load.

The samples were analyzed at the end of each storage study interval but after four months of storage the number of colonies in the surface of the osmotically dehydrated pineapple slices was undetectable. The microbial load in osmotically dehydrated pineapple slices after four month of storage was observed (<100 cfu/g) thus its reported negative for all the four samples.

NPRT

VPRT

NPLT

VPLT

Plate 9: Changes occurred after 3 months of storag

PRT

PLT

VPRT

VPLT

Discussions

5. DISCUSSION

The results obtained in the present investigation entitled‘Osmotic dehydration of pineapple slices (*Ananas comosus*)’ on different aspects of dehydration of pineapple slices and their packaging and storage are discussed below.

5.1. Kinetic study of pineapple cubes on water loss and mass variation.

5.1.1. Effect of concentration and temperature of osmotic solution on water loss behaviour of pineapple cubes.

Atmospheric “760 mm Hg” Pressure

Water loss increased with increase in temperature and time of immersion up to 150 min and then it decreased in all three osmotic solution, this may be due to reduction of moisture in pineapple slices to osmotic solution and gaining of sugars by the pineapple slices and after it moisture have reached to equilibrium between cellular fluids and osmotic solution along with volume and compactness of fruits solution (Barat *et* al., 2001). Our findings are in line with the findings of Kumar *et* al. (2006) and Fasogbon*et* al. (2013) who have reported significant loss of water with increase in immersion time up to 3 and 4 hrs in osmotic dehydration treatment. The present findings are in conformity with the observations reported by Alam *et* al. (2013). During the osmotic dehydration treatment on average the water loss of (34%) at 40 °C in 50 °B (43%) at 50 °C in 60 °B and similarly 46% in 70 °B water loss was observed (Fig. 4.1.1-a,b,c). Considering all the three temperatures and concentrations the concentration of sugar solution 70 °B at 40 °C was found most effective for reduction of water loss in pineapple cubes at atmospheric pressure.The water loss increased with increase in concentration of solution and temperature, this might be due to diffusion of water from diluted medium to concentrated solution (hypertonic solution) through a semi-permeable membrane until concentration equilibrium reaches (Kumar *et* al., 2006), they have also reported that there was maximum water loss at 70 °B and minimumat 40 °B. The increase in water loss with increase in sugar concentration which might be due to increase in proportion of water diffusion and gaining of solids by the pineapple slices from osmotic solution. As every 10 °B increase in concentration of sugar solution is equal in 10 °C increase of temperature in final water loss in osmotic dehydration (Pokharkar and parasad., 1998).

Vacuum pressure 435 mm Hg

The application of partial vacuum 435 mm Hg pressure initially up to first 15 min of osmotic process rapidly increased the rate of water loss till 210 min and then attained. This might be due to deformation of the tissue structure causing penetration of the osmotic solution and increasing thecontact area for mass transfer reported by (Mujica-Paz *et* al., 2003). Application of vacuum on guava for 15 min during osmotic dehydration process has also been reported by (Jefferson*et* al., 2010). The rate of water loss was higher at 40 °C in 70 °B, and it reached to equilibrium point after 150 min. However rate of water loss at the same vacuum was closely followed by at 60 °B and it reached to 30% later on attained equilibrium after 210 min. The least water loss 26% under the vacuum 435 mm Hg pressure in sugar solution of 50 °B at 40 °C reached equilibrium with the same duration of 210 min (Fig 4.1.2–a,b,c). This difference to become equilibrium might be due to different rate of water loss response of food tissue to the osmotic solution and temperature (Giangiacomo*et* al., 1987).

Although higher percentage of water loss was recorded at 40 °C followed by closely at 50°C and 30 °C, but it was statistically insignificant. Higher rate of drying at 40 °C may be attributed to the mass transfer characteristics created and its efficiency. Temperature used under the vacuum conditions had a significant effect on dehydration WL of apple slices till 40 °C, but the temperatures (>40 °C) caused softening of the tissues resulting lower dehydration Paes *et* al. (2008). The result of our experiment strongly supports findings of Paes *et* al. (2008). Similarly (Giangiacomo*et* al., 1987) reported that in osmosis process water loss is mainly controlled by characteristics of raw material tissues and the temperatures (>40 °C and <10 °C) changes the fruit structure which results lower dehydration.

Vacuum pressure 110 mm Hg

The rate of water loss during vacuum pulsed kinetics under vacuum110 mm Hg pressure showed a proportional relation with the osmotic temperature in all three concentrations. Increase in level of vacuum had a significant effect on faster dehydration of pineapple cubes and maximum water loss 42% and it attained equilibrium at 50 °C in 70 °B, whereas time of immersion decreased to 120 min which was the fastest to equilibrium point in present study. This may be due to hydrodynamics mechanism during the time of osmotic process, under the vacuum conditions where gas occluded in the intercellular spaces of tissues might haveremoved and again in restoring to atmospheric pressure the pores are filled by osmotic solution (Deng and Zhao, 2008; Panadés *et* al., 2006; Fermin and Corzo, 2005; Fito, 1994).

Similarly pineapple cubes dipped in 60 °B at 50 °C reached to equilibrium point in 150 min and maximum water loss (39%). These observations are in concurrence with senior researchers Barat *et* al. (1998) who reported that higher osmotic pressure favours dehydration of the water from the fruit. Paz *et* al. (2003) observed that in vacuum condition increase in concentration of solution has a significant impact on water loss of mango, melon and apple, and Ramalloa *et* al. (2012) found that equilibrium of sugar content increased from 45 to 54 % as the temperature rose from 30 to 50°C.

5.1.2. Effect of concentration and temperature of osmotic solution on mass variation behaviour of pineapple cubes.

Atmospheric Pressure

Trend of kinetic of mass variation in all pressure levels, sugar concentrations and temperatures was similar to water loss behaviour. Variation in mass of cubes during 240 min of osmosis increased with increase in time of immersion. Decrease in mass variation increase till 150 min when the samples were dipped in 50 and 60 °B, and maximum mass variation 23% was recorded at 50 °B at 50 °C. With the increase in syrup concentration the mass variation also increased and it reached equilibrium in 120 min when samples were dipped in 70 °B at 50 °C, while mass variation (24%) and 25 % was recorded in result of 60 °B and 70 °B respectively. According to (Rastogi *et* al., 2002 and Lerici *et* al., 1985), the mass transfer during osmotic dehydration depends on several factors like concentration of solution, nature of molecular weight of osmotic agent,temperature of solution and cell structure. Findings of our experiments are also in concurrence with the study of Khan *et* al. (2012) who has also reported that the rate of solid gain was very high during initial osmosis process and solid gain increased with the increase in concentration and temperature of osmotic solution.

Vacuum 435 mm Hg pressure

The result of mass variation was found close to the atmospheric condition with some little changes. The trend of mass variation was initially slower in 50 and 60 °B, with increase in time of immersion and it was reached to equilibrium point within 120 min, then started to decrease with increase in time of immersion. However mass variation was decreased faster when the samples were treated with 70 °B and it reached to equilibrium point with the period of 150 min. The highest mass variation 20% was occurred in pineapple cubes when dipped in 70 °B at 40 °C, followed by 17% in 60 °C at 50 °C. Sugar solution of 50 °B at 40 °C temperature showed the maximum 14% variation in mass reduction of pineapple cubes during kinetic study of osmosis dehydration.This may be explained due to response of cell structure with the vacuum pressure and because of unavailability of agitation during osmosis process(Rastogi *et* al., 2002 and Lerici *et* al.,1985). Similar observations have been reported by Ferrari *et* al. (2010) in mass transfer kinetics of melon during osmotic dehydration.

Vacuum 110 mm Hg pressure

Mass variation of pineapple cubes increased with increase in level of pulse vacuum applied for pineapple cubes in all the concentrations and temperatures. The equilibrium point for mass reduction was found at 210 min after immersion for the samples treated in 50 °B and it decreased to 150 min with the increase of concentration to 60 °B and to 120 min in 70 °B. Highest mass variation 23% was observed in pineapple cubes immersed in 70 °B at 50 °C, followed by 22% in 60 °B at 40 °C, and the least 20% in 50 °B at 50 °C. The phenomena of increasing in mass reduction of pineapple cubes at higher might be due to more pronounced to affect the mass reduction by the presence of gasses in the food tissue at this vacuum level as well as after releasing vacuum in atmospheric osmosis duration (Deng and Zhao, 2008; Panadés *et* al., 2006; Fermin and Corzo, 2005; Fito, 1994). Similarly (Fito & Chiralt, 1997; Rodriguez & Barbosa-Canovas 2000) have also reported that highest mass transfer rate is due to variation of osmotic pressure between cell wall of food and solution. The cause of faster and higher variation at 110 mm Hg than 540 mm Hg pressures might be due to changes occurred to cell structure by application of vacuum pulse during osmosis process and this makes pores of the tissues for better mass transfer, this process might have accelerated the process with the increase of solution temperature.

The vacuum has shown a great impact on water loss and mass variation, while the kinetics of water loss and mass variation at atmospheric pressure was more favourable. This might be due to presence of continuous agitation in atmospheric osmosis process, which was unfortunately impossible under vacuum oven used for osmosis process with the application of vacuum held without agitation. Initial increase of mass variation with time during the osmotic dehydration process, reaching a reduction from (~23% to 13-16%) of the initial mass after 4 hrs of osmotic dehydration(Fig. 4.4 to 4.6).Similar observations have been reported by Silva *et* al. (2014), who attributed this behaviour to the selective permeability of the cell membranes allowing for the transport of small molecules such as water, but restricting the transport of larger molecules such as sucrose, and hence reduce the diffusion of sucrose through the cell tissue.

5.1.3 Drying kinetics of pineapple cubes with respect to osmosis solution temperature

Non-linear regression analysis was done to determine the best model to explain the variation in moisture ratio with time during osmotic dehydration of pineapple cubes. According to Alibas (2014) who applied numerous models to explain the drying kinetics for celery leaves and determination of the effective moisture diffusivities and activation energy. In this study more than ten models were applied to fit the kinetics of moisture ratio in pineapple cubes.

Based on degree of fit as determined using variance explained, coefficient of regression, percentage of loss, visual fit, three models (Diffusion model; Wang and Singh model and Logistic model) were selected.

Further, root-mean-square-error (RMSE) and chi-square (χ^2) tests were conducted for these models, depicts the RMSE values for fit of data using the three models at various pressure levels of osmosis. Since lowest value of RMSE indicates least difference in the observed and computed values by the particular model, it was imperative that logistic model gave the best predicted values for the observed data. Alibas (2014) explains in his study of mathematic modeling for moisture diffusivity that a thin-layer drying model in which R^2 value is closest to"1" and RMSE, chi-square (χ^2) valuethe smallest was chosen tobe the most optimum model. Hossain *et* al. (2001) used to calculate the Sorption isotherms and heat of sorption of pineapple with the help of BET model and they reported that the value of root mean square error (RMSE) represents fitting ability of a model in relation to the number ofdata points. The smaller the RMSE value indicates the better the fit of the model. Kingsly *et* al. (2009) studied the effect of high pressure on texture and drying behaviour of pineapple and he reported that value of (R^2> 0.9), indicating the goodness of a fit.

Similarly, from chi-square test (χ^2), which is considered a better indicator of degree of fit to non-linear estimations, it was observed that logistic model gave the least values (Fig. 4.1.8). Further to test the efficacy of this model, parity chart was drawn observed and predicted values (Fig. 4.1.9). An excellent fit to the model was hence observed. Thelower the value of the reduced (χ^2), the better is the goodness offit Alibas. (2014).

Drying kinetics of pineapple cubes at atmospheric pressure and effect of temperature on moisture ratio of pineapple cubes immersed in 50 °B osmotic solution. Depicted in (Fig. 4.1.10), it can be seen that at 40 °C, the rate of moisture loss was the highest, then 50 °C followed by 30 °C. This might be due to higher rate of moisture loss in the pineapple cubes at 40 °C and cause of slower rate 50 °C, could be due to shrinkage of cubes which might have caused case hardening. Similar observation have been reported by Silva *et* al. (2014) where they recommended (>40 °C and <10 °C) for higher and efficient water loss with maintaining acceptable quality and texture of the product. Similar observations were recorded for pineapple cubes immersed in 70 °B solution at atmospheric pressure. The higher rate of water loss in atmospheric condition than the vacuum environment may be due to agitation, which increases the potential of osmotic solution for better moisture transportation. Water loss and solute gain depends on degree of agitation, among othersfactors (Teles *et* al., 2006). Rastogi *et* al. (2002) explained that agitation is indeed one of the keyfactors during osmosis dehydration.

5.1.4. Parameters of the logistic model as function of temperature, °Brix and pressure.

Values calculated with the help of logistic fit model for coefficients ‘a*’ and ‘b*’ of pineapple cubes during osmotic dehydration depicted in (Fig. 4.1.12 and 4.1.13). The coefficient ‘b*’, was found to decrease with increase in temperature of osmotic solution in all sugar concentrations. Also, ‘b*’ values decreased with increase in osmotic potential. Being directly proportional to moisture ratio, higher value of ‘b*’ indicates higher moisture retention and vice versa.

The curve of coefficient variation (b*) for 435 mm Hg pressure showed a vast range in both 50 and 60 °B with respect to osmotic temperature, while it was very little in 70 °B. This might be due to efficiency of higher concentration which takes the moisture out of the tissue in all temperatures (30-50 °C used in this experiment). The range of (b*) for 70 °B varied from (0.785 to 0.787), thus in 70 °B all the three temperatures were found significant with slight variation in favour of 40 °C. Similarly 40 °C was found the most suitable temperature drying kinetics for coefficient (b*) value calculated by logistic equation. Our findings are supported with the observations made by reaches (Kumar *et* al., 2006) who reported higher diffusion of water in higher concentrations of sugar.

Increasing in vacuum level to 110 mm Hg pressure showed the same trend as in case of 435 mm Hg pressure, but found more significant on coefficient (b*). Variation in all the concentrations of osmotic solution at 110 mm Hg pressure was found lower than 435 mm Hg pressure with respect to temperature levels, as expected, the (b*) value decreased upon increase in temperature of osmosis, since moisture loss was more at higher temperatures. The least variation found at 70 °B ranging from 0.682 to 0.715, whereas it ranged from (0.684 to 0.813) in 60 °B and (0.742 to 7.95) in 50 °B. Thus the concentration of solution in study of kinetics of water loss with respect to coefficient variation of (b*) was more significant than osmosis temperature in osmotic dehydration of pineapple cubes under vacuum condition. The clarification of this phenomenon might be due creation of more contact are by application of vacuum and more osmotic solution reaches to food tissue (Mujica-Paz *et* al., 2003)

The comparison of the all three variation in coefficient (b*) the least variation was observed at 435 mm Hg pressure and it was highest at atmospheric condition (760 mm Hg pressure) which indicatesunder the vacuum pressure, the moisture removal was higher in same syrup concentration and osmotic potential conditions from initial time of osmosis, however temperature was found more responsible for moisture loss at atmospheric condition than the vacuum under the same condition.the lower variation of (b*) at atmospheric condition can be explained to the fact that under agitated condition there was always a better mass transfer since there was always a fresh unsaturated interface at the surface of osmossed particles.

The coefficient “a*” which as inversely proportional to moisture ratio was found significantly affected by application of treatments. The coefficient “a*” without considering the trend of decrease *viz* increase in its value shown in the curve in both the vacuum pressures, and it was different but in case of atmospheric pressure. This shows the significance application of vacuum on moisture ratio of pineapple cubes (Fig. 4.1.12, 14 & 16).

The variation in moisture ratio of pineapple cubes studied under all pressures and temperatures without considering the specific concentration of sugar solution had lower effect of moisture loss of the pineapple cubes at 30 to 40 °C, but the trend of moisture ratio rapidly started to increase at >40 °C up to 50 °C, Silva *et* al., (2014). The rate of moisture ratio decrease slightly faster at 30 °C under atmospheric condition as compare to vacuum, but at temperature >40 °C the rate of moisture ratio had a sudden fall and water loss was taking place very fast in both the vacuum pressures of 110 mm Hg and 435 mm Hg, but the rate of decrease in moisture ratio higher under atmospheric condition at the same temperature. Considering of all the 216 samples, the moisture ratio was highest at 30 °C under atmospheric pressure and lowest at 110 mm Hg at 40 °C under atmospheric condition compared to 50 °C under 435 mm Hg and 110 mm Hg. The significance effect of atmospheric pressure on water loss behaviour of pineapple cubes during kinetics study of osmotic dehydration of pineapple could be due to agitation as discussed in previous paragraphs.

5.2. Osmotic pre-treatments and drying methods for dehydrated pineapple slices using response surface methodology (RSM).

Response surface methodology RSM was used to estimate the main effects of osmotic dehydration process on water loss WL and solid gain SG in pineapple slices. This statistical analysis has been recommended by researches done inside the lab to reduce number of treatments as well as no replications are needed. This method has its own replications based on software calculations and analysis the accuracy of the research. TheBox-Behneken designwas used Table 4.2.1 for temperature (30, 40& 50°C), vacuum level (atmospheric “760”, 435 mm Hg &110 mm Hg pressures), sugar concentration (50, 60 & 70°B). The sample to solution ratio was kept constant (1:4) for 180 min. Based on previous experiment done for osmotic dehydration technology and the Kinetic study we did on the WL, SG and WR of pineapple cubes among them of different durations were used for osmotic dehydration. The time duration for osmotic dehydration was found optimum 180 to keep a better balance between water loss and solid gain in pineapple slices.

5.2.1. Weight Reduction (WR)

Weight reduction of the pineapple slices increase with increase in level of vacuum, degree brix (°B) and temperature. The values recorded for weight reduction due to vacuum, concentration and temperature was found statistically significant. The rate of weight reduction in all 15 runs of osmotic dehydration of pineapple slices varied from (7.63% to 13.00%) and the maximum weight reduction was found in 435 mm Hg pressure, 70 °B sugar and 50 °C temperature. This difference in behaviour might be due to difference in size of contact surfacebetween fruit pieces and the syrup, different structure, compactness of tissues and also otherintrinsic properties which could vary in fruit to fruit and variety to variety (Pedapati and Tiwari, 2014).Our findings are also in corroborate with the study of osmotic dehydration of apple slicesby (Moura *et* al., 2005 and Aouar*et* al., 2006). The variables such as pressure and temperature had also been reported significant in weight reduction during osmotic dehydration (Corzo and Gómez, 2005)

5.2.2. Solid Gain (SG)

Solid gain during osmotic dehydration of pineapple slices increased with increase in sugar concentration. The increase in solid gain during osmosis process could be due to diffusional differencesbetween water and sugar, related to their differentmolar masses (Torregiani, 1993). The findings of our experiment are in support to the findings of (Paes *et* al., 2008) who have reported that the solid gain was not greatly affected by temperature during osmotic process. Many other authors have reported that the increase in water loss had been observed with respect to increase in °Brix of sugar solution and temperature (Islam and Flink, 1982; Hawkes and Flink, 1978; Ponting, 1966). Though the data present in Table 4. 2. 2 shows that the highest solid gain took place at 50 °C but estimated regression coefficients calculated from all 15 runs of RSM design Table 4. 2. 5 indicates that solid gain of dehydrated pineapple slices was affected with increasing in concentration of sugar solution rather than temperature.

5.2.3. Water loss (WL)

Pineapple slices showed a range of 6.45% to 16.46% water loss behaviour during application of different treatments for osmotic dehydration. The pineapple slices started loss of water even they were treated with 50 °B sugar at 30 °C temperature and the rate of water loss increased with the increase in all three parameters of experiment (vacuum levels, °B and temperature). Maximum water loss was found when the samples treated at vacuum level of 435 mm Hg pressure and sugar solution of 70 °B at 50 °C temperature. The increase in water loss could be due to combination of level of vacuum, temperature, and concentration of sugar syrup which might have greater impact on water loss and solid gain of the food under osmotic dehydration. Our observations are in line with the result of (Paes *et* al.,2008) who reported that vacuum and temperature during vacuum osmo-dehydration had significantly increase in water loss rate during osmotic dehydration, similarly (Campos *et* al., 2012) reported that increase in solution temperature and concentration during osmotic dehydration influences the solid diffusivity and this causes greater water loss.

5.2.4. Colour

Colour of the product is the first and main parameter which decides consumer acceptability or rejection of the product. The effect of vacuum, temperature and concentration of sugar solution on total colour and L* (lightness) in present experiment indicates that temperature during osmotic process had significant effect on total colour of pineapple and the pineapple slices treated in sugar solution at lower temperatures had higher total colour values. This might be due sensitivity of colour pigments with thermal processing that at lower temperatures pigments are not affected by the temperature and had high colour retention Valencia*et* al. (2011). Pointing *et* al. (1996) suggested a maximum solution temperature of 49 °C during osmotic dehydration for a better colour retention. Calculation of estimated regression coefficients shows that total colour of dehydrated pineapple was affected by vacuum and L* value (Table 4. 2. 7 & 8), our observation are contradictory with the findings of Corzoa *et* al. (2005) who have reported that vacuum pulse was found not efficient for improvement of total colour in osmotic dehydration, but at the same time our findings are in support of his work that temperature and concentration of osmotic solution is affecting the L* value increasingly in dehydrated product.

5.2.5. Water Activity (A_w)

A little variation in A_w in all the samples was recorded and A_w varied from (0.328 to 0.423) after osmotic dehydration followed by tray drying. Though the osmotic dehydration significantly affect the $A_w$in all the samples under all the treatments, but effect of vacuum, temperature and °B of osmotic solution was not found statistically significant on A_w of the dehydrated pineapple slices. This might be due to effect of osmotic dehydration in all the treatments which might have reduced the A_w (Valencia*et* al., 2011). The results of our experiment are in corroborate with the findings of Silva *et* al. (2014) who reported that over all the osmotic dehydration had significantly decreased water activity of fresh pineapple in all the temperatures and concentrations. Reduction in water activity of the food during osmotic dehydration makes the environment unfavourable for microbial growth (Alzamora *et* al., 1995).

5.2.6. Ascorbic Acid

Osmotically dehydrated pineapple slices could retain up to (52.44 mg/100mg) ascorbic acid. Concentrations of sugar solution and temperature during osmotic dehydration have influenced on retention of ascorbic acid. The reduction in ascorbic acid may be due to the degradation of ascorbic exposing at higher temperature Zanoni *et* al. (2000).The comparison of retention of ascorbic acid in dried tomato was studied by Fuchigami *et* al. (1995) and they reported that osmotically treated tomato had 65% retention of ascorbic acid more than untreated tomatoes after 1 year. Osmotic treatment lowered the quality changes in green peas as well as had a good retention of ascorbic acid in frozen samples compared to untreated samples Giannakourou and Taoukis (2003).

The estimated regression coefficientTable 4. 2. 9 shows that ascorbic acid content of dried pineapple was affected by all three experimental parameters of vacuum, concentration and temperature, in fact ascorbic acid was the most affected parameter found in present study. Our findings are in line with the findings of Ramalloa and Mascheronib (2012) who explained that 45 °C was found the best temperature in osmotic dehydration of pineapple and added that the degradation of ascorbic acid was very high at 75 °C, which shows that ascorbic acid is highly susceptible to drying temperature. Similar result was observed by Orikasa *et* al. (2008) in study of kiwi fruit. The effect of concentration of osmotic solution using fructose sugar reported by Manzanares *et* al. (2004) shows that good quality and ascorbic acid retention in osmoticaly dehydrated quince in 55 °B sugar and 30 °C of temperature.

5.2.7. Organoleptical Evaluation

5.2.7.1 Texture

Texture of osmotically dehydrated pineapple scored 8 out of 9 in sensory evaluation. Application of vacuum affected the texture of dehydrated pineapple as compared to atmospheric pressure this might be due to opening of pores by both osmotic pressure and vacuum pressure which are acting as an external force to open the pores Ferrari *et* al. (2011). Our observations were also explained by Chavan and Amarowicz. (2012) on osmotic dehydration of fruits including mango and pineapple. Similarly Silveira*et* al. (1996) found that osmotically dehydrated pineapple with application of vacuum was scored more than sample vacuum was not applied.

5.2.7.2 Taste

The variation in taste of dehydrated pineapple was found from 5.3 to 7.6 out of 9 in sensory evaluation, this variation could be due to effect of different treatment parameters. Similarly estimated regression coefficient was found in affecting the taste of pineapple which might have exhibited due to the concentration of sugar solution and temperature in taste of dehydrated pineapple slices. Chaudhari *et* al. (2015) reported that pineapple slices dipped in 50 °B sugar solution had a better acceptability for its taste than the sample dipped in 60 °B.

5.2.7.3 Odour

The odour of dehydrated pineapple slices scored 7.3 by the sensory panel which indicates a positive effect on acceptability of odour after drying of the product. The estimated regression coefficient also shows the interaction of all three treatments which indicates higher acceptability of odour in dehydrated pineapple slices, however it was statistically non-significant. The result has also been supported by Silva *et* al. (2014) who have reported that osmotic dehydration controlled the aroma losses and increased the sensory acceptance. Similarly (Fraeye *et* al., 2010) reported that aroma of the strawberries were minimally affected by high pressure treatments during osmotic dehydration.

5.2.10 Appearance

Increasing in level of vacuum affected the appearance acceptability of dehydrated pineapple as indicated in estimated regression coefficient, similarly temperature and concentration of solution had also affected the appearance of product significantly. Our findings are also in corroborate with Changrue*et* al. (2008) who reported that osmotic pre-treatment in microwave vacuum drying lead to higher acceptance of dried product with respect to appearance. Similarly Sridevi and Genitha (2012) reported that appearance and overall acceptability of osmotically dehydrated pineapple was increased with increase in sugar solution of 40-60 °Brix and temperature of 30-50 °C respectively.

5.3. Packaging and storage conditions for osmotically dehydrated pineapple slices.

5.3.1. Moisture content

Moisture content of osmotically dehydrated pineapple slices increase with increase in storage period at both room temperature and low temperature. The gain of moisture during storage was more in samples packed in normally pack and stored at room temperature (RT) than stored at low temperature (LT). Moisture content increased from 5.2% at to 6.7 % during storage. The increase in moisture content of dehydrated pineapple slices might be due to transport of air moisture from atmosphere. The gain of moisture was more in the slices packed in normal packaging as compared to vacuum packed samples. This might be due to elimination of air from the packed slices by the evacuation of vacuum and replacing the air by vacuum, same observation was reported by (Sagar and Kumar, 2009). The dried pineapple slices stored at low temperature and was packed normally (NPLT) showed slight increase in its moisture content this can be because of controlled RH at refrigerated condition as reported by Manzano *et* al. (1997) during storage of dehydrated fruits and same results have been reported by (Kumar *et* al., 2008; Rahman *et* al., 2010 and Mizanur *et* al.,2012). These findings are also in corroborate with the work of Chetti *et* al. (2012) who found that the combination of vacuum packaging and low storage temperature had very tinny effect on moisture content.

5. 3.2.Ascorbic acid

Ascorbic acid is very susceptible to temperature and very less affected by vacuum during storage, the degradation of ascorbic acid started from the 1st month of the storage at room temperature. After four month storage the maximum ascorbic acid was lost in the dehydrated pineapple sample stored at room temperature (NPRT) which shows almost 50% decrease from initial ascorbic acid content in dehydrated pineapple slices (47.62 mg/100g) and it reached to (24.42 mg/100g). Similarly the samples which were packed using vacuum technology VPRT showed slightly better result than the normal packed sample and it decreased ascorbic acid to (28.86mg/100g). Our finding corroborates the work of (Othman, 2011 and Dhar *et* al., 2008) who reported the decrease in ascorbic acid content of fresh pineapple during storage. Hussein *et* al. (2000) concluded their finding from study of different packaging method on ascorbic acid degradation of broccoli and green pepper that neither partial vacuum nor complete vacuum packaging are having significant effect on retention of ascorbic acid during storage at room temperature.

The effect of low temperature storage was found highly significant on retention of ascorbic acid in osmotically dehydrated pineapple slices, normal packed samples and storedat low temperature NPLT could retain (44.4 mg/100g) and vacuum packed VPLT also retained (44.4 mg/100g). The retention of ascorbic acid in the dried samples stored at low temperature might be due to the susceptibility of ascorbic acid to high temperature (Fennema, 1993; Sedas *et* al., 1994) they reported that several factor could affect degradation rate of ascorbic acid such as water activity, temperature, pH, storage time and metal ions, Sedas *et* al. (1994) had also reported that under the fixed condition of the temperature and relative humidity had significantly affected the degradation of ascorbic acid in pineapple during storage.

5. 3.3. Total Sugar

Total sugar increased with increase in storage period in both mode of packaging and storage condition. The osmotically dehydrated pineapple stored at room temperature NPRT had the highest sugar increase in all the samples and it increased from (51.03% to 60.04%) after 4 month of storage, likewise the VPRT sample had higher increase of sugar in the samples stored at room temperature than stored at low temperature. This could be due to faster hydrolysis of polysaccharides at roomtemperature during storageSagar and Kumar. (2009), they also reported that the sugar content of osmotically dehydrated mangoes increased during storage at room temperature. Although our finding contradicts the finding of Paul *et* al. (2014) who reported that the content of total sugar was decreased in dehydrated pineapple cubes during storage intervals.

Storage temperature conditions affected the total sugar of osmotically dehydrated pineapple slices significantly. Though NPLT and VPLT had a very less increase in total sugar 54.71% and 54.42% respectively in dried pineapple, but still vacuum packaging had slightly better result in controlling the sugar content. This might be due to relative humidity and moisture which could be affected by storage temperature, thus low moisture content in refrigerated stored dehydrated pineapple slices made it able to slow increase its sugar content and it was close to initial product sugar content. Our findings are in line with observations of Liu *et* al. (2006) who reported that the quality of potato retained well and sugar remained at low level while it was stored for 8 months at 10 ºC.

5.3.4. Total phenolics

Total phenolics changed significantly with increase in storage period. The total phenols decreased in dried pineapple from its initial value of (86.39 mg GAE/100g) to (9.20 mg GAE/100g) after 4 month of storage at room temperature in normal packed pouches and the maximum retention was observed at vacuum packed sample stored at low temperature (16.54 mg GAE/100g). The decrease in total phenols may be due to break down of it to other compounds during storage and this process can be accelerated at higher temperature and presence of air. Our observations are in line with Bennet *et* al.(2011) who reported that phenolics can be either reduce or might generate chemical derivatives during storage. Similarly Gálvez*et* al. (2012) reported that total phenolics content is significantly decreasing at higher temperatures.

5.3.5. Total carotenoids

A very little amount of total carotenoids i.e. (0.43 ±0.02 mg/100g) was recorded in fresh pineapple slices. While in case of dried samples by applying the same method of estimation it could not be detected. The reason may be loss of carotenoids during dehydration at higher temperature due to degradation of total carotenoids exposing at the higher temperature during dehydration process. Gupta*et* al., (2011) also reported a very low level of low carotenoids which even cannot be measured after drying in the pineapple slices. Our finding are supportive with the findings of Gardner *et* al. (2000) who reported that the carotenoid concentration was very low in pineapple juice and below the limit of detection.

5.3.6. Water activity (Aw)

There was increasing trend in A_w in the samples packed at different mode of packaging during storage. The maximum increase in water activity was observed in the sample NPRT and it increased from 0.44 to 0.55 after 4 months of storage period. The changes in water activity of NPLT sample was also higher 0.51than that of packed in vacuum pouches 0.45 in VPRT and 0.45 in VPLT pineapple samples. The significant changes in normal packaging of dehydrated pineapple slices may be due to presence of oxygen gas.

5.3.7. Hardness

Hardness of the dried pineapple slices decreased with increase in storage period, and maximum hardness was observed in the sample packed under vacuum and stored at low temperature. Although some difference in hardness of the samples stored at room temperature and low temperature was recorded, but the variation in hardness of normal packed and vacuum packed samples was highly significant. This difference might be due to evacuation of O_2 from pores of dried pineapple slices, which might have make the texture of the product softer and more elasticity. Kejing *et* al. (2013) reported that vacuum pulsed osmo-dried cherry tomatoes had a softer texture compered to osmo-dried samples because of vacuum affect on opening of pores, but the creation of vacuum in an aluminum pouch could cause destruction of those created pores and compress the samples due to environmental pressure from out of the storing pouch. Thus the vacuum packed samples were found to retain harder texture.

5.3.8. Total Colour

The effect of packaging conditions was highly significant on colour of the dehydrated pineapple slices during storage. The total colour changed more in the samples packed at normal pack and stored at room temperature and decreased from 78.94 to 62.33 throughout the storage period. Total colour change L* value is responsible for darkness of the sample and is having greater value compared to a* and b* values therefor the total colour is mostly presenting the lightness (white) and darkness (black) of the samples beside the other (yellow, red, green and blue) colours. These observations are in supportive to the result of Silveira *et* al., (1996) who has reported maximum colour degradation during storage of osmo-dried pineapple. Similarly the effect of storage was not significant while the dehydrated pineapple slices were stored at (NPLT) condition the total colour (ΔE) recorded (71.59) which shows a slight decrease from the initial colour of the product. The findings are in line with the finding of Silveira *et* al., (1996) that the colour of osmo-dried pineapple remained almost the same as original colour of the fruit when it was stored at low temperature of -27 ºC, this might be due to control of moisture and water activity at lower temperature. VPRT could retain the colour for one month and then colour degradation was appear in vacuum packed dried pineapple (VPRT) after 2 month of storage there was decreasing trend in (ΔE) and it reached to (64.60) after 4 months. Our findings are in accordance to the observation of Ozogul *et* al., (2004) who studied the effect of vacuum packaging on colour of sardines. The dried pineapple packed VPLT showed almost the same colour to the fresh pineapple and it had the least change in total colour after 4 month of storage (73.50), this could be due to significant interaction of vacuum and controlled temperature which restricts the browning and other parameters responsible for colour change such as A_w and moisture. The findings of Ozogul *et* al. (2004) shows that both the vacuum and modified temperature are having a very positive affect on colour retention of sardines during the storage.

5.3.9. Organoleptic evaluation

5.3.9.1. Colour

The storage temperature was found very significant in colour retention of dried pineapple slices during storage. The colour loss was recorded in normal packed sample at room temperature and it was well in vacuum packed sample. However the samples stored at low temperature have very close colour to original colour of fresh pineapple even after four month of storage. The change in colour may be due to gain of more moisture at room temperature and in case of non-enzymatic browning which highly pronounced at higher temperatures. Similar observations have been reported by Chwastek (2014) in frozen broccoli during 6 month of storage at -25 ºC.

5.3.9.2 Appearance

The normal packed samples followed by storage at low temperature were found most acceptable after 4 month of storage for appearance attribute. Vacuum packaging affected the appearance of the sample in a negative manner. The reason for better appearance of normal packed sample at low temperature storage could be due to the retaining of the original colour, shape and structure of the dried product similar findings have been reported by (Ibarz & Bermeijo, 1991; Ibarz, *et* al., 1989; Stamp & Labuza, 1983). In case of vacuum packed samples the shape, structure and colour of pineapple slices might have destructed by application of vacuum at room temperature.

5.3.9.3. Texture

Texture of the osmotically dehydrated pineapple slices, packed in normal pack and stored at room temperature was highly acceptable by sensory panel. Whereas the texture of dried pineapple slices had the same packaging mode but stored at room temperature scored same sensory score close to NPLT score for texture. Use of vacuum packaging technology was found negatively affecting the texture of dried pineapple slices. This may be due to the pressure of atmospheric force which occurred after creating the vacuum environment inside the pouches, and this force causes the destruction of pores and toughness of the product. As texture of the product is mostly affected by hardness so the changes in hardness during the duration of storage is highly responsible for the score of texture of the product.

5.3.9.4. Taste

Taste of the samples packed with different mode of packaging and storage temperature was acceptable after four months of storage. The most acceptable storage condition was found normal packaging with storage at low temperature. The reason for having a better taste in such a storage condition might be cause of the better retention of nutritional value and physical attributes. Silveira *et* al. (1996)

studied the osmotic dehydration of pineapple in atmospheric and vacuum environment and they reported that taste of product stored in sealed polypropylene pouches at 25 ºC was acceptable after 3 month of storage.

5.3.9.5. Odour

Storage temperature was found statistically significant for odour of dehydrated pineapple slices. Both normal and vacuum packed pouches stored at low temperature scored high sensory score for their odour, but samples stored at room temperature destructed their original odour of product. The destruction of odour at room temperature may be due to inhibition of volatiles and aromatic compound which are responsible for aroma and odour. In a recent study of chemical and physical properties of jack fruit affected during osmotic dehydration by Srinang *et* al. (2015) who have reported that odour of the osmotically dehydrated jack fruit was highly affected by temperature and vacuum.

5.3.9.6. Overall acceptability

Considering all parameters for organoleptic sensory and the grades given by sensory panel for overall acceptability of the product. The samples packed in two mode of packaging retain better acceptability up to 2 months of storage, however samples packed in normal packaging and stored at low temperature retain higher sensory score in respect to colour, taste, texture and overall acceptability even after four month of storage. This is may be cause of best suitability of the packing method and storage temperature for all the sensory attributes.

5.3.10. Microbial load.

The microbial load for all the samples was observed (<100 cfu/g) which counted as “no detection of colonies”. This might be due to presence of very low moisture content and low water activity, same findings have been reported by (Rao, 1977; Biswal & Le Maguer, 1989) who have reported that water activity is a major factor for microbial growth in food materials.

Summary and Conclusion

6. SUMMARY AND CONCLUSION

The present investigation entitled "Osmotic dehydration of pineapple slices" was conducted during the year 2013-15 at Indian Agriculture Research Institute (IARI), New Delhi. The experiment were conducted to standardize the concentration and temperature of osmotic solution on water loss, mass variation, drying kinetics, osmotic pre-treatments, drying method, packaging and storage behaviours of dehydrated pineapple slices.

The salient experimental findings are summarized below:

Water loss of pineapple cubes at atmospheric pressure increased with increase in time of dipping in all three sugar concentrations and temperature of osmotic solution up to 150 min and then decreased.In case of samples treated with 50 °B, 60 °B and 70 °B sugar solution, the 70°B sugar solution recorded maximum water loss 46% at 40°C after 150 min. The loss of water increased with increase in vacuum level. Water loss reduction increased with increase in time of dipping in all three sugar concentrations and it was higher at vacuum level of 110 mm Hg

On comparing of three different concentrations, temperatures and vacuum levels 70°B at 50°C under110mm Hg pressurefound most efficient for mass variation followed by 70°B at 40°C under435mm Hg pressure. The rate of mass variation (%) proportional to temperature was maximum 20%at 50°C in 210 min and it was minimum at 30°C. The time of immersion, temperature and concentration of solution were found to have directly proportional to the mass variation under110mm Hg of pressure in pineapple cubes.

Non-linear regression analysis was done to determine the best model to explain the variation in moisture ratio with time duration during osmotic dehydration of pineapple cubes. It was imperative that logistic model gave the best predicted values for the observed data.

The higher water los in osmosed pineapple cubes was recordedat higher osmotic potential while at lower concentration of osmotic solution the pineapple cubes there was less water loss at same temperature of osmotic solution.The coefficient "b*" was found to decrease with increase in temperature of osmotic solution in all sugar concentrations. Also "b*" values decreased with increase in osmotic potential. Being directly proportional to moisture ratio, higher value of "b*" indicates higher moisture retention and vice versa.The effect of temperature and osmotic potential on the moisture ratio was not much evident at 435mm Hg pressure level.

The percentage of water loss in dehydrated pineapple slices varied from minimum 6.45% to maximum 16.46% in 15 samples. It was observed that increase in level of vacuum had a significant effect on loss of water, the (p=0.016). Increase in °Brix (p= 0.016) has a significant effect on solid gain of pineapple slices.The total colour values recorded for all the 15 samples varying from 69.12to 81.78shows that vacuum is having a significant affect (p=0.1). The difference in water activity A_w of osmotically dried pineapple slices was not found statistically significant, whereas the process of osmosis had significantly affected A_w of the dried pineapple slices. Ascorbic acid was found most affecting from all the parameters while estimated regression coefficients was applied, the all three parameters were found significant (highest; 52.44 mg/100mg and lowest; 38.64 mg/100mg).

The different parameters of sensory test had been found significantly affected by most of the treatments applied. Texture of the dehydrated pineapple was significantly affected by application vacuum (p= 0.045). With regard to taste the osmotically dehydrated pineapple slices scored 6.4 in average was significantly affected by temperature of product (p= 0.031). Dehydrated pineapple slice scored 7.31 for its odour was affected by temperature and vacuum and found statistically significant at (p=0.1). Appearance was found to be the most affected parameter by the experimented treatments, vacuum (p=0.003), °Brix (p=0.025, vacuum*vacuum (p=0.037), temperature*temperature (p=0.001) and °Brix*temperature (p=0.000) were found effecting highly significant the appearance of dehydrated pineapple.

Storage temperature and mode of packaging both affected the moisture content of osmo-dried pineapple slices statistically significant. The moisture content increased from its initial content (5.22% to 6.73%) at room temperature and 5.64% at low temperature when the samples were packed in normal packaging material. Similarly moisture content increased to 5.99% at room temperature and 5.49% at low temperature when the samples were packed under vacuum.

The hardness of pineapple slices during storage was less in the sample packed in normal packaging and stored at room temperature, but it was higher in the sample packed under vacuum and stored at room temperature. However total colour of pineapple slices decrease with the increase in storage period. Storage temperatureand vacuum affected the total colour changes significantly during storage of dehydrated pineapple slices.

There was a great increase A_w from (0.44to 0.56) with the increase in days of storage. The initial water activity increased when samples were normally packed and stored at room temperature, meanwhile the slices packed under vacuum and stored at low temperature had very less increase in water activity(0.45).Ascorbic acid decreased with increase in storage period. The reduction in ascorbic acid was more in the samples packed in normal packaging material and stored at room temperature as compared to samples packed under vacuum and stored at low temperature. Vacuum and storage temperature affected the total sugar content of osmotically dehydrated pineapple slices at both the temperature and vacuum during storage. Total sugar of the dehydrated pineapple slices increase upto 4 month of storage and increase in total sugar was more in the sample when packed as normal pack and stored at room temperature as compared to samples packed with vacuum stored at low temperature.The total phenols decreased 12 times less than its initial amount in four months, when the slices were packed in vacuum pouches and stored at low temperature with a maximum quantity of (16.54 mg GAE/100g) while the initial amount was (86.39 mg GAE/100g) at time of packaging.

Storage temperature affected the colour of the pineapple slices significantly during storage, and it was decreased with increase in time of storage.Similarly appearance of dehydrated pineapple slices decreased with the increase in storage time.The score for texture of osmo-dried pineapple slices was highest in normally packed sample followed by stored at low temperature in comparison of pineapple slices packed normally and were stored at room temperature, whereas the vacuum packed samples scored very low score at the end of storage.The score of the taste was higher in normally packed slices stored at low temperature. Similarly vacuum packed dried pineapple slices stored at low temperature scored the highest sensory score at the four month storage.

The microbial load in osmotically dehydrated pineapple slices after four month of storage was observed (<100 cfu/g) which was reported as negative.

Conclusion:

1. Water loss of pineapple slices increased with increase in temperature and concentration of the osmotic solution.
2. The maximum water loss was observed at concentration of 70 ºB at 40 ºC.

3. Among the different combination of concentration, temperature and vacuum levels, 70 ºB *viz* 50 ºC under 110mm Hg pressure was found most efficient in reduction of mass of the pineapple slices.
4. The time of immersion, temperature and concentration of solution were found proportional to affect the mass variation of pineapple cubes.
5. Non-liner regression analysis was found the best model for explaining the variation in moisture ratio with time duration during osmotic dehydration of pineapple slices.
6. The ascorbic acid, phenol content and sensory score of dehydrated pineapple slices were affected by osmotic treatments such as concentration and temperature of the osmotic solution and time of immersion.
7. Increase in moisture content was higher during storage when the samples were packed under normal condition and stored at room temperature in comparison to samples packed under vacuum and stored at low temperature.
8. Ascorbic acid, sensory score, colour changes and phenolic content decreased with increase in storage period in all the samples.
9. The packaging of samples using vacuum technology followed by low temperature was found better retaining higher amount of ascorbic acid and total phenolic content as well as less colour changes and sensory score.

Abstract

<u>अनानाश की कतली का परासरणीय निर्जलीकरण</u>

वर्तमान अनुसंधान शीर्षक 'अनानाश की कतली का परासणीय निर्जलीकरण' के अन्तर्गत परासणीय विलयनों की सघनता और तापक्रम का मानकीकरण निर्जलीकृत अनानाश कतली की जल हानि, द्रव्यमान परिवर्तन, शुष्कन गतिकी, परासणीय प्रेरक निरूपण, शुष्कन विधि, पैकेजिंग और भंडारण आचरण आदि पर किया गया हैं। वायुमंडलीय दवाब पर अनानाश के क्यूब की जल हानि तीनों शक्कर की सघनताओं और परासणीय विलयन के तापमान पर डुबोने की समय अवधि बढानें के साथ – साथ 150 मिनट तक बढोतरी पाई गई और फिर उसमें कमी पाई गई है। अधिकतम जल हानि 70^0 बी सघनता और 40^0 सेल्सियस पर पाई गई है। अनानाश क्युब में 730मि. मी. एच. जी. दवाब पर डुबोने की समय अवधि तापमान और विलयन की अघनता द्रव्यमान परीवर्तन के समानुपातीय पाई गई है। अरेखिय प्रतिगमन गुणांक विश्लेषण द्वारा निर्धारित उत्तम प्रतिरूप द्वारा परासणीय पिर्जलीकृत अनानास क्यूब के नमी अनुपात में समय अवधि के साथ – साथ हुए परिवर्तन की समीक्षा की गई।

नमी अनुपात के समानुपातीय "b*" का उच्चमान यह दर्शाता है कि नमी का उच्चमान अवरोधनिय और विलोमतः है। निर्वात तकनीकी द्वारा पैक नमूनों का निम्न तापमान पर भंडारण ऐस्कार्बिक अम्ल, कुल फिनोलिक मात्रा और रंग परीवर्तन में कमी को परिणमतः अच्छा अवरोधी पाया गया और संवेदक आकलन पर भी उच्च प्राप्तांक वाला पाया गया है।

परासणीय निर्जलीकृत अनानाश कतली पर भंडारण तापमान और पैकेजिंग का तरीका दोनों को नमी की मात्रा में आंकड़ों की दृष्टि से महत्वपूर्ण ढंग से प्रभाव करने वाला पाया गया है। सामान्य तापमान पर आम पैकेजिंग सामग्री में पैक नमूनों में प्रारंभिक नमी की मात्रा 5.22 प्रतिशत से बढ़कर 6.72 प्रतिशत पाई गई और निम्न तापमान पर 5.64 प्रतिशत पाई गई हैं। इसी प्रकार जब नमूनों को निर्वात में पैक किया गया तो सामान्य तापमान पर नमी की मात्रा 5.99 प्रतिशत तक बढ गई।

भंडरण अवधि के दिनों की संख्या बढानें पर जल सक्रियता (A_w) में 0.44 से 0.56 तक सर्वोत्तम बढोतरी पाई गई है। परासणीय निर्जलीकृत अनानाश कतली में निर्वात और भडारण तापमान का कुल शक्कर की मात्रा पर दोनों तापमानों और निर्वात पर आंकडों की दृष्टि में महत्वपूर्ण ढंग से प्रभाव पाया गया है। इसी प्रकार निर्वात पैकेजिंग द्वारा निर्जलीकृत अनानाश कतली निम्न तापक्रम पर आंकलन में सर्वोच्च प्राप्तांक हासिल किया है। चार महीनें की भंडारण अवधि के पश्चात भी परासणीय निर्जलीकृत अनानाश कतली में सुक्ष्मजीवीय भार (<100cfu/g) पाया गया है जो कि त्रनात्मक घोषित किया गया है।

ABSTRACT

"Osmotic dehydration of pineapple(*Ananas comosus*) slices"

The present investigation entitled "Osmotic dehydration of pineapple slices" was conducted at division of Food science and postharvest technology, IARI, New Delhi during 2013-15 to standardize the pre treatments of concentration and temperature of osmotic solution and immersion time for better quality of dehydrated pineapple slices. Different parameters such as water loss, mass variation, drying kinetics and drying methodswere studied. To perform these parameters pineapple fruits were cleaned peeled and core was removed with the help of corer and knife than three concentration of sugar solution 50, 60 and ºBrix three different temperatures of 30, 40 and 50 ºC followed by three vacuum pulses atmospheric, 435 and 110 mm Hg pressures as well as immersion time ranging from 20 to 240 min were applied. Results showed that water loss in pineapple slices increased with increase in time of dipping in all three sugar concentrations and temperatures of osmotic solution up to 150 min and maximum water loss was recorded at a concentration of 70 ºB at 40 ºC. The time of immersion, temperature and concentration of solution were found to have directly proportional for reduction of mass variation at 110 mm Hg of pressure in pineapple slices. Non-linear regression analysis wasfound best model to explain the variation in moisture ratio with time duration during osmotic dehydration of pineapple slices. The packaging material of aluminium laminated polythene pouches (260 g) using vacuum technology followed by storage at low temperature storage was found better for retaining higher amount of ascorbic acid, total phenolic content as well as sensory score and less total colour changein dehydrated pineapple slices during four months of storage. Moisture content, water activity (A_w), total sugar contents and colour changes increase with increase in storage period, while ascorbic acid, total phenols and sensory score decreased with increase in storage period. However increase in moisture content, water activity, total sugar and colour changes as well as decrease in ascorbic acid, total phenols and sensory score were affected significantly by mode of pack and storage temperature during storage of dehydrated pineapple slices. During four months of storage of dehydrated pineapple slices product remained free from any microbial load in respect of yeast, mould and bacteria.

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