“Osmo-Air Drying of Ginger Slices”

M. Tech. (Agril. Engg.) Thesis

by

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CERTIFICATE-I

This is to certify that the thesis entitled **"Osmo-Air Drying of Ginger Slices"** submitted in partial fulfilment of the requirements for degree of **Master of Technology in Agricultural Engineering** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.), is a record of the bonafide research work carried out by **Mr. Rahul Sahu** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma (certificate awarded etc.) or has been published. All the assistance and help received during the course of the investigations have been duly acknowledged by him.

Dr. Ajay Verma
Date: 24/08/2009 (Chairman)

THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE

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CERTIFICATE-II

This is to certify that the thesis entitled **"Osmo-Air Drying of Ginger Slices**" submitted by **Mr. Rahul Sahu** to the Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.), in partial fulfilment of the requirements for the degree of **Master of Technology (Agricultural Engineering)** in the department of Agricultural Processing & Food Engineering has been approved by the Student's Advisory Committee after oral examination in collaboration with the external examiner.

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LIST OF NOTATIONS/SYMBOLS

%	per cent
^{o}Bx	degree brix
^{o}C	degree celsius
cm	centimeter
db	dry basis
et al.	*et alia*
g/g	gram per gram
h	hour
h/day	hour per day
ha	hectare
kg/cm^2	kilogram per square centimeter
kg/ha	kilogram per hectare
km/h	kilometer/hour
kPa	kilo Pascal
lm	lumen
m^2	square meter
mm	millimeter
m.c.	moisture content
m/s	meter per second
MT	metric tonne
min	minute
N	Newton
rpm	revolution per minute
µg/ml	micro gram per milliliter
v/w	volume by weight
η_e	exergetic efficiency
wb	wet basis

LIST OFABBREVIATIONS

Agril.	agricultural
Agril. Engg.	Agricultural Engineering
ANOVA	analysis of variance
ASAE	American Society of Agricultural Engineers
CCRD	Central Composite Rotatable Design
C.G.	Chhattisgarh
CIAE	Central Institute of Agricultural Engineering
Engg.	engineering
e.g.	for example
FAE	Faculty of Agricultural Engineering
FAO	Food and Agricultural Organisation
Fig.	figure
ICAR	Indian Council of Agricultural Research
I.G.K.V.	Indira Gandhi Krishi Vishwavidyalaya
i. e.	that is
M. Tech.	Master of Technology
No.	number
PE	polyethylene
RH	relative humidity
RSM	response surface methodology
SG	solid gain
WAI	water absorption index
WSI	water solubility index
WL	water loss
WR	weight reduction

Abstract

Osmo-Air Drying of Ginger Slices

BY

RAHUL SAHU

ABSTRACT

Ginger is an herbaceous perennial plant also known as *Zingiber officinale Roscoe*. It is a tropical herb extensively grown for its pungently aromatic underground stem or rhizome which is an important export crop valued for its powder, oil and oleoresin. Ginger is very important from therapeutic, nutritional and medicinal point of view. The ginger is having potential to standby all its important properties if it is suitably processed into various food products. Due to its pleasant pungent and spicy aroma, ginger is used in the manufacture of a number of products like ginger bread, confectionery, certain curried meats, soft cordials, ginger cocktails, carbonated drinks, ginger brandy, wine and beer in many western countries etc.

Response surface methodology was used to determine the optimum processing conditions that yield maximum water loss, weight reduction and minimum solid gain during osmotic dehydration of ginger slices. Te0mperature (25-65^{o}C), processing time (1-8 h), salt concentration (3-15%) and mass ratio (1:5-1:25) were the factors investigated with respect to water loss (WL), solid gain (SG) and weight reduction (WR). Experiments were designed according to Central Composite Rotatable Design with these four factors each at five different levels, including central and axial points. Experiments were conducted using water bath and hot-air oven. With respect to water loss, solid gain and weight reduction both linear and quadratic effects of four variables were found to be significant. For each response, second order polynomial models were developed using multiple linear regression analysis. Analysis of variance (ANOVA) was performed to check the adequacy and accuracy of the fitted models. The response surfaces and contour maps showing the interaction of process variables were constructed. Applying desirability function method optimum operating conditions were found to be temperature of 45.3^{o}C, salt concentration of 9.1%, mass ratio of 15.0 and treatment time of 4.5 h. At this

optimum point water loss, solid gain and weight reduction were found to be 14.4, 2.4 and 11.7% respectively. Quality analysis of osmo-air dried ginger slice was done according to Ranganna (2000) with 9-point hedonic scale. Average score of the sensory evaluation was 7 or above. On the other hand ANOVA analysis for sensory evaluation was also significant. Physico-chemical analysis of osmotically dehydrated ginger slices was investigated after optimization and drying at three different temperatures (40, 50 and 60^{o}C). It was found that the ginger contains about fat 6.28-6.3%, protein 8.48-8.52%, carbohydrate 66.1-66.5%, volatile oil 1.23-1.34% and texture (hardness) 6.12-6.9 N, colour L, a, b; 69.30-70.33, 4.68-4.87 and 34.01-34.59 respectively.

Date: 24/08/2009

Rahul Sahu

Dr. Ajay Verma
(Major Advisor)

Chapter-I

Introduction

CHAPTER-I

INTRODUCTION

Ginger is a tropical species native to South East Asia. It belongs to the family '*Zingiberaceae*'. Ginger has been used as a spice and medicine in India and China since ancient times. In India, ginger is being used from Vedic period and is called "Maha Aushidhi". The African and the Indians in East Africa uses ginger as a remedy for headachy by applying its paste on the head. Ginger has been found helpful in preventing cough and colds. Ginger is employed as a treatment for asthma, breathlessness, vomiting in many Asian countries. Ginger is available in chipped and powder form and as a powder extract.

India ranks first with respect to ginger production contributing about 50 per cent of total world's ginger production followed by China (21.41%), Nigeria (12.54%) and Bangladesh (10.8%) (Rao *et al.*, 2008). The production of ginger in India is shown in Table 1.1. India is exporting ginger mainly to Pakistan, Saudi Arabia, UAE, Morocco and USA etc. Presently 2,63,170 MT of ginger is produced in India from an area of 77,610 hectare. Indian ginger has high esteem in the global market because of its characteristic lemon like flavour. Table 1.2 shows export of ginger from India.

Table 1.1: Area, Production and Productivity of Ginger in India

Year	Area ('000 ha)	Production ('000 tonnes)	Productivity (kg/ha)
2001-02	90.8	318.0	3,502
2002-03	90.8	317.0	3,500
2003-04	85.1	301.9	3,548
2004-05	95.3	359.0	3,767
2005-06	110.6	391.2	3,537
2006-07	105.9	370.3	3,497

Source: http://www.indianspices.com

Table 1.2: Export of Ginger from India during 2003-04 to 2008-09

Year	Quantity (tonnes)	Value (lakhs)
2003-04	5,000	2,340.50
2004-05	14,908.13	5,929.40
2005-06	10,890.43	4,580.59
2006-07	9,661.34	4,777.77
2007-08	8,332.91	3,295.08
2008-09	3,229.70	1,581.75

Source: http://www.indianspices.com

Food Preservation has become an integral part of the food processing industry. Another major reason of food preservation is in demand is that there is a long gap between production and the actual consumption of food commodities. As there is rise in demand for food preservation is on the look out for more long lasting methods of preservation which will be effective in maintaining the quality and freshness of the commodity. The main purpose of preservation is to fight against factors such as:

- Non-enzymatic chemical reactions
- Enzymatic chemical reactions
- Microbial decomposition

Food and food products are highly perishable due to their high moisture content. Decreasing the moisture content of fresh foods to make them less perishable is a simple way to preserve these foods. The removal of moisture prevents the growth and reproduction of microorganisms causing decay and minimizes many of the moisture-mediated deteriorative reactions. It brings about substantial reduction in weight and volume, minimize packing, storage, transportation costs and enables storability of the product under ambient temperatures. Dehydration increases the storage stability of food and food products making them available throughout the year. Dehydrated products also play a great role in processed foods of all kinds (*i.e.*, in soups) and ways to achieve high quality dehydrated products are desired.

Osmotic dehydration is one of the effective method for preservation; it is a viable process for the partial removal of water from cellular material, such as fruits, vegetable and spices without a phase change and is often applied as a pretreatment process. The osmotic dehydration consists of food immersion in hypertonic solution (e.g. salt, sugar, sorbitol, glycol etc.). The concentration difference drives water from the food to the solution in order to dilute the hypertonic solution. This process reduces the physical, chemical, biological changes and improves quality, retains the nutrients during drying (Lenart *et al.*, 1984).

Osmotic dehydration differs from conventional drying method in two major ways. Firstly, a soaking process (immersion) achieves both a dewatering and a formulation effect of solid products. Secondly, a soaking process does not generally produce a stable product. Thus, osmotic dehydration is useful as a pre-processing step prior to drying and freezing of foods including fruits, vegetables, spices, meat and sea food products (Lerici *et al.*, 1985; Collignan and Raoult-Wack, 1994; Rahman *et al.*, 2001). The beneficial effects of osmotic dehydration include higher quality of the final product and lower energy requirements.

Osmotic dehydration followed by air drying can appear to be a promising and cost effective method of preservation for spices. The main purpose of drying of ginger is to enhance storability, improve quality and minimize packaging, handling and transportation cost. In general drying of ginger is indigenously performed under sun light. This is a very time consuming method and the method produces the inferior quality of the product. In order to reduce the time of drying and to obtain a good quality final product, mechanical dryers that use heated air are mostly employed for drying ginger now a days. Besides giving a better quality product, it also avoids the dependency on the vagaries of weather and reduces microbial contamination of the product.

Dried ginger have varied applications in culinary preparations, confectionery and bakery industries, in the manufacture of perfumes, toiletry-products, meat processing, soft drinks, wine making and above all in Ayurvedic and Allopathic medicines. It is expected that the world demand will double in the next five years. Indian ginger can play a major role in achieving this level of demand being the largest producer of ginger and processing almost every product for export.

Considering the emerging demand and importance of dried ginger for the production of various value added ginger products, a research work entitled "Osmo-Air Drying of Ginger Slices" was planned to carry out the osmotic dehydration of ginger slices followed by hot air oven drying method at different combinations with the following objectives:

Objectives:

1. To study the osmotic dehydration characteristics of ginger slices.
2. To study the air drying characteristics of osmotically dehydrated ginger slices.
3. To evaluate the quality of dried ginger slices.

Osmo-air drying of ginger slices is conducted at different combinations. The findings were utilized for suggesting suitable osmo-air drying combination in order to obtain good quality ginger for the production of value added products.

Chapter-II

Review of Literature

CHAPTER-II

REVIEW OF LITERATURE

This chapter deals with the review of the research work carried out by various investigators on osmotic dehydration, process optimization through response surface methodology, drying and quality evaluation/chemical analysis of different food (fruits and vegetables) in particular. Efforts have been made to incorporate the information as for as possible. The review of literature is presented under following broad headings:

- Process optimization using Response Surface Methodology (RSM)
- Osmotic dehydration of food (fruits and vegetables)
- Drying and osmotic dehydration
- Influence of concentrations of osmotic solution
- Influence of temperature on osmotic dehydration
- Influence of sample size on osmotic dehydration
- Drying conditions
- Drying methods and equipments
- Quality evaluation/chemical analysis of ginger

2.1 Process optimization using Response Surface Methodology (RSM)

Response Surface Methods are designs and models for working with continuous treatments when finding the optima or describing the response is the goal. The first goal for Response Surface Method is to find the optimum response. When there is more than one response then it is important to find the compromise optimum that does not optimize only one response. When there are constraints on the design data, then the experimental design has to meet requirements of the constraints. The second goal is to understand how the response changes in a given direction by adjusting the design variables. In general, the response surface can be visualized graphically.

Singh *et al.* (2008) conducted a study on osmotic dehydration of fresh pineapple at different sucrose concentrations, temperature, time and fruit solution

ratio. The response variables considered were: water loss, solid gain, ratio of water loss to solid gain (WL/ SG) and weight reduction. A central composite rotatable design (CCRD) was used as experimental design. A response surface methodology (RSM) was used to analyze and predict the optimum conditions for pineapple osmotic dehydration. All model terms were significant in water loss except quadratic level of temperature whereas in solid gain, the model terms were significant except fruit to solution ratio at quadratic level. The optimum dehydration parameters corresponded to 62°Bx sucrose concentration, 30°C temperature, 6 h time and 1:6 fruit to solution ratio to obtain water loss of 48.41%, solid gain of 10.9%, WL/SG ratio of 4.4 and weight reduction of 37.0%.

Erbay and Icier (2009) worked on response surface methodology to optimize operating conditions of the drying of olive leaves in a tray drier; desirability function used as the methodology for the optimization. Optimization factors were air temperature (40-60^{o}C), air velocity (0.5-1.5 m/s) and process time (240-480 min) while investigated responses were total phenolic content, antioxidant activity loss, final moisture content and exergetic efficiency (η_e). The optimum conditions for drying of olive leaves in a tray drier were determined to obtain the criteria; minimum phenolic content, antioxidant activity loss and maximum η_e for moisture content value below 6% and the optimum condition was found to be the temperature of 51.16^{o}C with the air velocity of 1.01 m/s for the process time of 298.68 min. At this optimum point phenolic content, antioxidant activity loss, moisture content and η_e were found as 10.25, 41.88, 6.0 and 65.50%, respectively.

Otoniel *et al.* (2008) used response surface methodology to optimize operating conditions of thin layer drying of coroba slices. A rotatable central composite design was used to develop models for the responses. The independent variables were air temperature, air velocity and drying time. The responses were final moisture content, drying rate and energy efficiency. The second-order polynomial models with transformed responses were developed from experiment data to generate 3D response surfaces and contour plots. Applying the multi response optimization the optimum operating zone was located within the intervals from 89.7-91.2^{o}C, from 64-71 min for air temperature and drying time respectively, and air velocity fixed at 1.08 m/s. Applying the desirability functions the optimum

conditions were temperature equal 90.6^{o}C, drying time equal 69 min and air velocity equal 1.08 m/s.

Eren and Figen (2007) conducted an experiment using response surface methodology to determine the optimum processing conditions that yield maximum water loss, weight reduction and minimum solid gain, water activity during osmotic dehydration of potatoes. Temperature (20-60^{o}C), processing time (0.5-8 h), sucrose (40-60% w/w) and salt (0-15% w/w) concentrations were the factors investigated with respect to water loss (WL), solid gain (SG), weight reduction (WR) and water activity (a_w). Experiments were designed according to Central Composite Rotatable Design with these four factors each at five different levels, including central and axial points. Experiments were conducted in a shaker (Thermoshake-Gerthardt) with constant agitation of 200 rpm and solution to sample ratio of 5/1 (w/w). With respect to water loss, solid gain, weight reduction and water activity, both linear and quadratic effects of four variables were found to be significant. For each response, second order polynomial models were developed using multiple linear regression analysis. Analysis of variance (ANOVA) was performed to check the adequacy and accuracy of the fitted models. The response surfaces and contour maps showing the interaction of process variables were constructed. Applying desirability function method optimum operating conditions were found to be temperature of 22^{o}C, sucrose concentration of 54.5%, salt concentration of 14% and treatment time of 329 min. At this optimum point water loss, solid gain, weight reduction and water activity were found to be 59.1 (g/100 g initial sample), 6.0 (g/100 g initial sample), 52.9 (g/100 g initial sample) and 0.785, respectively.

Chakraborty *et al.* (2007) designed experiments using response surface methodology to study the effects of salt solutions and their concentration, soaking time and cooking time on quality of instant pigeonpea dhal and to optimize their levels. Sodium carbonate, sodium bicarbonate and ammonium carbonate were used individually and in combination. The salt concentration varied from 1.93-4.73%. The soaking time ranged between 22 and 38 min. Cooking time was in the range 95-146 s. The results of the study showed that instant pigeonpea dhal could be prepared by soaking dhal in salt solution, cooking and drying at 65^{o}C. The soaking time and cooking time showed significant effect on expansion ratio and rehydration ratio of

pigeonpea dhal, while salt concentration had insignificant effect. Ammonium carbonate was most effective in its effect of rendering instantization characteristics to the pigeonpea dhal. In general, the samples with more expansion ratio exhibited higher rehydration ratio. The expansion ratio and rehydration ratio were optimized and common range of parameters was selected by overlapping their contour plots. The optimum conditions were different for different salt solutions.

Lee *et al.* (2006) used response surface methodology (RSM) for the determination of optimum extraction temperature and time to produce an acceptable banana juice extract. Banana juice was extracted using hot water extraction method at different extraction temperature (35-95^{o}C) and time (30-120 min). The effects of the extraction conditions on juice yield, total soluble solids (^{o}Bx), banana odour and taste were studied by employing a second-order central composite design. The coefficient of determination, R^2, for juice yield, total soluble solids (^{o}Bx), banana odour and taste were greater than 0.9. Analysis of the regression coefficients showed that temperature was the most important factor that affected characteristics of the banana juice extract as it exerted a highly significant influence ($p<0.001$) on all the dependent variables. An increase in extraction time and temperature of hot water extraction resulted in an increase in juice yield, total soluble solids, banana odour and taste of the banana extract. Based on surface and contour plots, optimum conditions for hot water extraction of banana juice were 95^{o}C for 120 min.

Uddin *et al.* (2004) investigated water and sucrose transfer during osmotic dehydration of carrot slices using response surface methodology with the sucrose concentration (40-60%), temperature of sucrose solution (40-60^{o}C) and immersion time (0.5-6.0 h) being the independent process variables. Quadratic regression equations describing the effects of independent process variables on the water loss and sucrose gain were developed. It was found that immersion time and concentration of sucrose solution were the most significant factors affecting the water loss during osmotic dehydration of carrots followed by temperature. Effect of temperature and time were more pronounced for sucrose gain than the concentration of sucrose solution. It is suggested that the regression equations obtained in this study can be used to find optimum conditions for the desired sensory and physical properties of sweet carrot products such as preserves.

Otoniel and Eddie (2004) optimized the osmotic dehydration of the cantaloupe using the desired function methodology. Cantaloupe cylinders were cut and weighted, initial humidity and ^{o}Bx were measured, then four cylinders were osmo-dehydrated in solutions of sucrose of give concentration and temperature by a stipulated time. The conditions of dehydration were established by means of a central composite rotatable design for temperatures, concentrations and times between 40-50^{o}C, 45-55^{o}Bx and 60-120 min respectively. Weight, humidity and ^{o}Bx were determined in each cylinder after dehydration in order to calculate the mass loss, water loss and ^{o}Bx increase. These response variables were fitted to predictive models applying multiple linear regressions. Applying the method of the desired function, the dehydration was optimized in 37.95^{o}C, 41.6^{o}Bx and 132.30 min in order to obtain weight loss equal to 0.11 g/g, water loss equal to 0.33 g/g and ^{o}Bx increase equal to 12.3^{o}Bx/g.

2.2 Osmotic dehydration of food (fruits and vegetables)

Many researchers have studied different aspects of osmotic dehydration like the solute to be employed, the influence of process variables on drying behaviour and the quality of the final products. The quantity and rate of water removal depend on several variables and processing parameters. In general it has been shown that the concentration of solution, immersion time, temperature, solution to sample ratio, specific surface area of the food and by using vacuum, stirring and continuous re-concentration are few variables affecting the osmotic dehydration process.

Mishra (2007) studied on osmo-solar drying of bottle gourd (*lagenaria siceraria*) to compare the effect of the concentration of the osmotic agents on osmotic dehydration. The salt solution with 5, 10, 15, 20, and 25% (w/w) concentrations were used for osmotic dehydration at the mass ratio of 1:10, 1:20 and 1:30 at 40, 50 and 60^{o}C for a period of 1, 3, 5, 7 and 9 h followed by solar drying. The maximum moisture content observed was 93.4% (wb) for samples osmotically dehydrated at 40ºC for 1 h at 1:10 fruit to osmotic solution at 5% concentration. The minimum moisture content was 46.9% (wb) for samples osmotically dehydrated at 60^{o}C for 9 h at 1:30 fruit to osmotic solution at 25% concentration. The weight reduction, water loss and solid gain were very fast during the initial period of

osmosis but equilibrium did reach even after 9 h. The solid gain varies from 22.4% (9 h, 25% concentration, 60ºC, 1:30 mass ratio) to 4.69% (1 h, 5% concentration, 40ºC, 1:10 mass ratio). The maximum water loss was 59.5% observed for samples osmotically dehydrated at 60^{o}C for 9 h at 1:30 fruit to osmotic solution of 25% concentration. The minimum water loss was observed 14.5% for samples osmotically dehydrated at 40^{o}C for 1 h at 1:10 fruit to osmotic solution of 5% concentration. Weight reduction varies from 38.9% for samples osmotically dehydrated at 60^{o}C for 9 h at 1:30 fruit to osmotic solution of 25% concentration to 10.7% for samples osmotically dehydrated at 40^{o}C for 1 h at 1:10 fruit to osmotic solution of 5% concentration. During the process of solar drying of 9 h bottle gourds cubes, the air temperature inside the cabinet varies from 44-81^{o}C and relative humidity inside the chamber was measured 34-58%. The minimum value of final moisture content of osmo-solar dried bottle gourd cubes was 8.3% at 60^{o}C for sample of 1:10 mass ratio and maximum value of final moisture content was 24.4% at 60^{o}C for 1:30 mass ratio**.**

Bhagyalakshmi (2006) investigated osmotic dehydration of bottle gourd (*lagenaria siceraria*). The osmotic dehydration operation of bottle gourd was conducted with commercial salt (5, 10, 15, 20 and 25%) at different temperatures (40, 50 and 60ºC) for different time of osmotic dehydration (1, 3, 6 and 9 h), and fruit to osmotic solution mass ratio of (1:30, 1:20 and 1:10). The minimum moisture content was found to be 47.7% (wb) for samples osmotically dehydrated at 60ºC for 9 h at 1:30 fruit to osmotic solution of 25% concentration, whereas the maximum moisture content was observed (93.6%) for the sample dehydrated at 40ºC for 1 h at 1:10 fruit to osmotic solution of 5% concentration level. The solid gain, water loss and weight reduction by the samples was found to be increased with the advancement of the dehydration time.

Camacho *et al.* (2006) worked on quantifying the flow of soluble micronutrients from the grapefruit to the osmotic solution and to dehydrate the fruit when recycling it in successive osmotic dehydration operations, without re-concentrating. Osmotic dehydration was carried out for 3 h at 30°C with a fruit rate 5:1 using a 55°Bx sucrose solution. Soluble solids (°Bx), water activity (a_w), pH, ascorbic acid, citric acid, galacturonic acid and major minerals were measured in the

fruit and in the osmotic solution as a function of the number of uses (up to 8). Of this study allow the osmotic solution to be reused for at least eight cycles without significant changes in the water activity of the obtained fruit. From this point of view, the reuse of the osmotic solution becomes an advantage, as it can be used as an ingredient in new food formulations, with the presence of natural compounds coming from fruit.

Aves and Wang (2005) studied osmotic dehydration process of acerola fruit. The process was carried out at a temperature of 25 and 60°C. Frozen acerola were blanched in water (80°C for 3 min) and dehydrated using binary and ternary solutions. The concentration of sucrose ranged from 30-60% (w/w) for binary solution and from 20-50% for ternary solution with 10% of salt. Responses of water loss, solid gain, solid gain/water loss ratio and weight reduction were evaluated. The best conditions were determined by using solid gain/water loss as a process parameter. The chosen conditions were a binary solution with 60% (w/w) of sucrose and a ternary solution of 50% of sucrose plus 10% of salt, both at a temperature of 60°C.

Moura *et al.* (2005) evaluated mass transport phenomena in general and osmotic dehydration processing in particular in three apple varieties Gala, Gold, and Fuji. The apples samples were dehydrated in sucrose solution of 50% (w/w) at 30°C and 110 rpm of agitation. The ratio of foodstuff to osmotic solution was 1:20. The mass transfer kinetics of different apple varieties has presented different behaviour during the dehydration. The apple vs. Gala has presented the highest water loss and solid gain. The apple *vs.* Gold presented a lower tendency to solid uptake.

Ramallo and Rodolfo (2005) conducted a study on water loss (WL), solid gain (SG) and variation in concentration of glucose and fructose during osmotic dehydration of pineapple slices (3 mm thick) in sucrose solution 60% (w/w) at three temperatures 30, 40, and 50°C. It showed that solute content was a linear function of the water content in the pineapple fruit during osmotic dehydration and this ratio was independent of temperature.

Revaskar and Kudra (2005) conducted a study on osmo-convective drying of onion slices for 10, 15 and 20°Bx NaCl concentration for 1 h and reported 6.3% weight reduction, 10.0% water loss and 6.75% solid gain for 20°Bx concentration.

He also reported that drying of onion slices occurred only in falling rate period and the average effective diffusivity varied from 0.78 x 10^{-10} to 1.301 x 10^{-10} m^2/s.

Bellmawr *et al.* (2004) evaluated the properties of a shelf-stable watermelon product made from osmotic dehydration and forced-air oven drying. Sucrose syrup at two different concentrations, 50 and 10°Bx, was used for soaking 3 x 3 x 3 cm cubes of watermelon flesh. A control watermelon at 9-10°Bx was also used. After 2 h of sucrose-syrup soaking, samples were dehydrated at 60°C in a forced air oven for 31 h with sampling at 0, 2, 7, 19, and 31 h. Samples were evaluated for colour, texture, and water activity at each of the sampling times. The osmotic dehydration process resulted in a watermelon product of better structure and colour than simple forced-air drying, but it did not significantly increase the drying rate.

Jain *et al.* (2004) studies on osmotic dehydration of papaya cubes. Ripe papayas (Carica papaya) of 'Taiwan red' variety were cut into 10 mm thick cubes and were pretreated with 0.5% calcium chloride solution with hot water at 80^{o}C and subsequently transferred in 1% sodium metabisulfite solution for 15 min. The pretreated cubes were dehydrated in sugar (sucrose) solution (50, 60 and 70^{o}Bx) for 2, 4, 6, and 8 h at room temperature. Water loss, weight reduction and solid gain were determined. The maximum value of water loss, weight reduction and solid gain was found to be 75.52, 68.94 and 4.55% respectively for papaya cubes dehydrated in 70^{o}Bx sugar solution for 8 h. The data were analyzed and regression equations were predicted. It was found that the equations for water loss, weight reduction and solid gain all followed the second order polynomial form. The coefficient of correlation for all the experimental data was more than 0.9. It was also observed that maximum reduction in weight and water loss occurred during the first 2 h of osmotic dehydration. The osmotically dehydrated papaya cubes were then air dried in a cabinet drier at 50^{o}C. The dried cubes had a wrinkled surface with squeezed cells and dark colour.

Cruz and Menegalli (2004) revealed the kinetics of osmotic dehydration of Aubergine using sodium chloride as osmotic agent, followed by hot air drying to achieve the proper final moisture content of storage. Osmotic dehydration kinetics was performed at different concentrations of salt (5, 10 and 15% w/w), different temperatures (25, 35 and 45°C) and different times of immersion. After osmotic

treatment, the product was dried at four temperatures (40, 50, 60 and 70°C) during 5 h. No browning was detected in samples storage by 6 months dried at 60 and 70°C, so no thermal injury was detected and the inactivation of polyphenol oxidase was well inactivated with the procedure adopted. Based on the behaviour of the osmotic dehydration kinetics and solid gain, the best conditions of the process seems to be 20 min of osmotic treatment time, temperature 35°C and saline concentration 10% (w/w).

Raghavan and Sunjka (2004) dehydrated cranberries (osmotically dehydrated) and dried to low water contents using one of following four methods: hot air drying, microwave-assisted convective drying, freeze-drying, and vacuum drying. Quality evaluation was performed on all samples, including sensory evaluation (appearance and taste), texture, color, water activity, and rehydration ratio. There was no significant difference in color measurements and water activity. Few differences in texture were found, except for freeze-dried cranberries, which had a lower toughness compared to the other drying methods including commercially available dried cranberries.

Sereno *et al.* (2004) investigated on kinetics of osmotic dehydration of pumpkin and modeling such dehydration kinetics. Dehydration process was performed using sodium chloride as osmotic agent. Pumpkin cylinders (diameter: 1.5 cm) osmotically dehydrated in varying concentrations of 5-25% (w/w), temperature 10-40^{o}C and concluded that salt and water diffusivities increased with temperature, and no dependence on osmotic solution concentration was observed

Mascheroni *et al.* (2004) evaluated mass transfer in banana and apple slices treated by osmotic dehydration in sugar solutions and followed through weight loss and solids gain. Concluded that during osmotic dehydration there is a rapid increase in weight loss at short process times and later processing occurs at lower rates. So no significant weight changes are attained by long process times. Mass transfer in apple, that having more open structure is faster than for banana.

Maura and Menegalli (2003) reported the water and sucrose effective diffusion coefficients behavior in potato tubers when immersed in aqueous sucrose solution 50% (w/w) at 27^{o}C. Water and sucrose concentration profiles were measured as function of the position for 3, 6 and 12 h of immersion. Analysis of

binary effective coefficients as a function of concentration and position, demonstrates that cellular tissue promotes high resistance to diffusion in the tuber and also the elastic contraction of material influences the diffusion.

Moreira and Sereno (2001) found the effects of temperature, solution concentration and solution flow rate on osmotic dehydration/impregnation rate during immersion of apple cylinders in sugar solutions at low temperatures (<25^{o}C). Water and sucrose mass transfer coefficients were calculated. Analysis of results suggests that solute gain by the sample be controlled by diffusion inside the material while water loss is governed by mixed internal external flow. Also analyzed that shrinkage be essentially due to the water removal/solid gain and offered a simple way to predict such changes during industrial processing.

Saputra (2001) studied osmotic dehydration of pineapple effects of sugar type, sugar concentration, immersion time and temperature on the mass transfer of osmotic dehydration were studied using pie shape slices (7 mm thick with its centre cork thrown away) of fresh pineapple (Queen variety, 90% maturity). The dehydration process was performed using two type of sugar as an osmotic agent (glucose and sucrose), three levels of sugar concentration (50, 60, and 70%), three levels of temperature (30, 50, and 70^{o}C), and three levels of immersion time (3, 6 and 9 h). Following the osmotic dehydration process, the pineapple was dried at 70^{o}C for 48 h. The mass transfer was then calculated and analysed statistically. Sugar type, concentration, temperature and length of immersion have a significant effect on the mass transfer of osmotically dehydrated pineapple. The highest mass transfer of pineapple was found by using sucrose at the concentration of 70%, temperature 50^{o}C and 9 h of immersion time.

Kar and Gupta (2001) conducted an experiment on osmotic dehydration characteristics of button mushrooms. Osmotic drying behaviour of button mushrooms (*Agaricus bisporus*) was experimentally studied in relation to temperature (25, 40 and 55^{o}C) and solution to sample ratio (4, 6 and 8) at a fixed brine solution concentration of 15%. Osmosis could remove almost 35% of the initial moisture in 1 h using 15% brine solution. The modelling of moisture loss, salt gain and mushroom solids loss revealed that out of power law, log, generalized exponential and Page's model, Page's model could describe the moisture loss pattern

most accurately, whereas salt gain and solid loss could be best described by power law and log models, respectively.

Rahman *et al.* (2001) investigated on osmotic dehydration of potato: equilibrium kinetics. Osmotic dehydration kinetics of potato slices and cubes was studied using sugar syrup of different concentrations and temperatures. The initial concentration of sucrose was varied from 30-65% and temperature was varied from 22-80^{o}C. The equilibrium coefficients for solids ranged from 0.84-1.55 and for water it ranged from 0.70-1.05. The equilibrium coefficient for solids increased with the increase in temperature while it decreased with the increase in syrup concentration. However, the equilibrium coefficient for water decreased with increasing temperature and it increased with the increase in syrup concentration. A multiple regression analysis of experimental data was carried out to correlate equilibrium coefficients with dimensionless temperature and syrup concentration.

Singh *et al.* (2001) studied on osmotic dehydration of carrot shreds for Gazraila preparation. Dehydration of carrot shreds was carried out by concentrating the material first in sucrose solution (50^{o}Bx) at room temperature prior to drying in cabinet drier at 55^{o}C. Half of the initial moisture content was removed during the initial 30 min of osmosis and additional 6 h were required to reduce the moisture content of the osmosed carrot shreds to 5.8%. On the other hand, for the un-osmosed carrot shreds, the drying time was 12 h at 55^{o}C. The moisture sorption isotherm studies revealed that the un-osmosed dehydrated carrot shreds were more hygroscopic as compared to the osmosed dehydrated sample and required a lower RH for safe storage. Gazraila made from osmosed dehydrated shreds received higher scores for all sensory parameters.

Pokharkar (2001) revealed the kinetic model for osmotic dehydration of Green Peas prior to drying. Green peas were osmotically dehydrated in sodium chloride-water solutions (5, 10 and 17% sodium chloride by weight) and three temperatures (20, 30 and 40^{o}C). Movement of salt and water was modeled for water loss from and salt uptake by the green peas. Green peas were dipped in 10% sodium chloride-water solution at 30^{o}C for 30 min and air dried in a fluidized bed dryer. Colour, texture, flavour and overall acceptability scores indicated that the dehydrated product was organoleptically acceptable.

Rahman and Lamb (1990) reported increased water loss and solid gain with the increase of sugar concentration and temperature in osmotic dehydration of pineapple and reported the rate of sucrose diffusion as a function of solute concentration and temperature.

Lerici *et al.* (1985) observed that addition of small quantity of NaCl to osmotic solutions increased the driving force of the drying process. Water activity of final product not only depends on the water activity of the osmotic solution but also on the gain of solids, which was determined by factors such as composition of syrup and sample shape.

2.3 Drying and Osmotic Dehydration

Giraldo *et al.* (2004) investigated osmo-dehydration of blackberry (*Rubus glaucus Benth*) with three sweetening agents. Osmotic dehydration of blackberry using 3 different syrups namely sucrose, reverse sucrose and cane syrup with identical initial concentration conditions (70^{o}Bx mean temperature of 20^{o}C and relative humidity of 65%) was performed in the Fruit and Vegetable Laboratory of the Universidad Nacional de Colombia, Sede Medellin, Colombia. Results revealed that cane syrup had greater osmotic potential (69.2%) than reverse sucrose (54.5%) and sucrose (50%), which was measured as the percentage weight loss of the blackberry samples. With the dehydration process of drying with hot air forced convection at 1.5 m/s velocity and 55^{o}C for 24 h, it was possible to reduce the humidity of products dehydrated by sucrose, reverse sucrose and cane syrup to 27.3, 30.8 and 25.9% respectively, and improve the packaging and storage conditions, making the product more stable against microbial contamination. Sensory evaluation of dehydrated blackberries conducted by 10 trained panelists before and after packaging and storage revealed that the product osmo-dehydrated by reverse sucrose syrup was the most acceptable before packaging, while the product osmo-dehydrated by sucrose syrup was the most acceptable after packaging.

Debnath *et al.* (2004) worked on rehydration characteristics of osmotic pretreated and dried onion. The effect of osmotic pretreatments (10% sodium chloride for 1 h or 50% sucrose for 3 h treatment) on rehydration kinetics of dried onion was studied over a range of temperatures (25-65^{o}C) and compared with an

untreated (control) sample. The effective diffusion coefficients for water and solute were determined by considering the rehydration process to be governed by Fickian diffusion. The diffusion coefficients for water absorption and solute infusion were found to be in the range 1.96×10^{-9} to 8.04×10^{-9} and 2.94×10^{-9} to 5.53×10^{-9} m^2/s respectively. Osmotic pretreatment resulted in a decrease in the diffusion coefficient of water as well as an increase in the diffusion coefficient of solute during rehydration. Decrease in the diffusion coefficient of water was due to an increase in the proportion of ruptured and shrunken cells caused by osmotic treatments, which in turn resulted in reduced ability of dried onion tissue to absorb water. The increase in diffusion coefficient for solid during rehydration was higher in the case of osmotic pre-treated material, some of the solids absorbed during osmotic dehydration were not retained in the cell matrix and dissolve faster than the constitutive onion dry matter.

Sousa *et al.* (2003) evaluated the products obtained by the banana's osmotic dehydration followed of drying. Two banana products were obtained through osmotic dehydration, one under atmospheric pressure and one under vacuum, with the drying complement in the stove. Sensorial, physico-chemical and microbiological analysis of these products were conducted during storage for 120 days at 23.4-34.1^{o}C and 33-81% relative humidity. Results showed that the products maintained their quality beyond microbiological stability during storage. Only the colour showed variation.

Alves and Silveira (2002) investigated drying of tomatoes osmotically dehydrated and not osmotically dehydrated. The drying of tomatoes was studied with the purpose of obtaining one product more resistant at the time and to facilitate its storage. To reach this objective, osmotic dehydration was conducted where sucrose and NaCl were used as the osmotic agents. The influence of varying agitation and drying temperature on the drying process was determined. The chemical and physical properties of the tomato fruit peel were also studied, with the intention of improving the dehydration. Another stage of this work consisted of the drying of osmotically dehydrated and non-dehydrated tomatoes using two driers (vacuum drier and convective drier) with varying temperature, air velocity and vacuum pressure. To evaluate the quality of the product, chemical analyses of the

parameters were accomplished. Results show the importance of the osmotic dehydration of tomatoes and the influence of the drying process on the final product, as influenced by the different driers.

Grabowski *et al.* (2002) evaluated the drying characteristics of osmotically pretreated cranberries - energy and quality aspects. This study reports on finish drying of osmotically pretreated (dehydrated and sugar-infused) cranberries (*Vaccinium macrocarpon*). The halved fresh berries pretreated in a standard osmotic solution (67.5^{o}B at 50^{o}C for 5 h) were then freeze-dried, vacuum-dried and air-dried in various driers (cabinet-air-through, fluid bed, pulsed fluid bed, and vibrated fluid bed driers) to identify the best drying technology. Energy consumption and product quality were chosen as the comparison criteria. The best product quality, quantified by the anthocyanins content, rehydration ratio, colour and taste, was noted for freeze-dried berries. As all other drying methods gave similar, albeit slightly lower quality products than freeze-drying, the selection of a drying method could be based on the unit heat consumption. The vibrated fluid bed and the pulsed fluid bed should be favored because of the highest energy efficiency. Even though sugar infused into cranberries during osmotic pretreatment reduces drying rates during the second drying period as compared to untreated berries, osmotic dehydration reduces the total energy consumption on top of the preferential sensory characteristics of the final product.

Krokida *et al.* (2001) studied effect of osmotic dehydration pretreatment on quality of french fries. Osmotic dehydration as a pretreatment before frying in order to produce low-fat french fries was examined. A relationship between frying kinetics and the type of solution used for osmotic dehydration before frying of french fries has been developed. The effect of osmotic dehydration on the structural properties (apparent density, true density, specific volume and internal porosity) and colour parameters (lightness, a, b) of french fries was also investigated. Four types of solutions (sugar, NaCl, maltodextrin 12 and maltodextrin 21) were used. The results showed that osmotic pretreatment had a significant effect on oil uptake and moisture loss of french fries, as well as on the structural properties and colour parameters of french fries. Osmotic dehydration pretreatment decreased oil and moisture content of french fries, while the porosity and colour increased.

Waliszewski (1994) investigated effect of pH, temperature and sucrose concentration on its hydrolysis rate during osmotic dehydration process. Sucrose is a very important agent in osmotic dehydration of tropical fruits. Acidifying sucrose with organic acids accelerated osmotic dehydration but caused darkening and quality deterioration during the subsequent drying process and final product storage. Effects of pH (4-10), temperature (50, 60 and 70^{o}C) and sucrose concentration (50, 60 and 70^{o}Bx) on sucrose hydrolysis rate were investigated. In the pH range 6-10 the extent of sucrose hydrolysis was insignificant and did not depend on temperature and sucrose concentration. But with decrease of pH below 5.0, sucrose hydrolysis increased significantly, depending on temperature, time and the concentrations of hydrogen ions and sucrose.

Sankat and Castaigne (1992) studied banana dehydration: osmotic, air and solar effects. Ripe banana slices 10 mm thick were osmotically dehydrated in sugar solutions of 35, 50 and 65^{o}Bx conc. for as long as 52 h, at 30^{o}C. Weight loss, moisture content and total soluble solids of the slices were measured. The rate and extent of these changes were strongly influenced by the strength of the osmotic solutions, and at least 48 h were required for the process to approach equilibrium. Osmotic treated and fresh banana slices were also air dried at 40, 60 and 80^{o}C. Drying was entirely in the falling rate period, and first and second falling rate drying constants were established. While increases in drying air temperature positively influenced the drying rate of fresh fruit slices, for osmotic treated slices drying at 80^{o}C reduced the drying rate, possibly due to caramelization and case hardening. Dried, osmotic treated bananas with added SO_2 had an attractive, yellow colour compared to the dull, dark brown colour of dried, fresh fruit slices. Finally, osmotic treated bananas can be dried in simple, low cost direct solar driers and the moisture content reduced from 197-22% (db) in 6 days.

2.4 Influence of concentration of osmotic solution

Giraldo *et al.* (2004) worked on osmotic dehydration of Jack fruit (*Artrocarpus integrifolia*). Jackfruit was dehydrated with 40, 50, and 60°Bx sucrose solution at 30°C for 3 h. Osmotic treatment decreased water contents. Water activity

decreased with the increase of sucrose solution concentrations. The data showed that drying time decreased with the increase of the concentration osmotic solutions.

Nieto *et al.* (2004) studied micro and macro structural changes in apple slices during osmotic dehydration. Samples were immersed into 25% glucose and 34.6% sucrose aqueous solutions at 30°C and examined for thickness, bulk and solid-liquid densities, porosity, water loss, solid gain and microscopic aspects. The changes in bulk density, porosity and volume of apple tissue along osmotic process were supported by micro structural and structural observations and explained by considering osmosis as multi component diffusion process through porous media and due to the relaxation of viscoelastic shrunken cell walls.

Lenart and Flink (1984 a) studied the osmotic drying of potatoes and reported the importance of the lowering capabilities of water activity by the salt as compared to sucrose for the same level of concentration. They also defined the terminology for mass transport data for osmotic dehydration. The mass transport data indicate the overall exchange of solute and water between fruits and osmotic solution. The water loss can be defined as the net loss of water from the product on the initial weight basis. The weight reduction can be defined as the net weight lost on initial weight basis. The solid gain is the net uptake of solids on initial weight basis.

2.5 Influence of temperature on osmotic dehydration

Ponting *et al.* (1966) were first to study the influence of processing variables such as pretreatment, temperature of solution and additives on the mass transfer in osmotic dehydration of various fruits and reported 50% reduction in weight in the apples, using sugar solution of 60-70% solids. The process resulted in superior quality product and needed no SO_2 treatment to prevent loss of flavour.

2.6 Influence of sample size on osmotic dehydration

Falade and Aworh (2005) sensory evaluation and consumer acceptance of osmosed star apple and African mango, African star apple (*Chrysophyllum albidum*) were immersed in sucrose solutions of 44, 52 and 60°Bx in water bath at 27°C and 40°C for 8 h. About 10 and 15 mm slices of African mango (*Irvingia*

gabonensis) were immersed in sucrose solutions of 52, 60 and 68°Bx in water bath at 27 and 40°C for 10 h. Osmotic dehydration was evaluated by the water loss (g water/g initial mass) and solids gain (g solids/g initial mass). Water loss and solids gain increased with increasing degree of fruit ripeness, immersion time, concentration and temperature of sucrose solution. Water loss and solids gain increased with decreasing slice thickness of African mango.

2.7 Drying Conditions

Michalik and Bakowski (1994) tested the suitability to drying of 9 varieties of onion grown in Poland. It was reported that the 3 mm thick slices takes 2-3 h at 65ºC for drying up to 9% moisture content.

Sutar (1986) investigated the effect of drying air temperature on drying characteristics of ginger and its quality over a temperature range of 40-70ºC. Based on the organoleptic quality and volatile oil content of the dried product an air temperature of 60-70ºC was found suitable for ginger drying. The drying rate curves indicated that ginger drying process did not have a constant rate period and that in falling rate period ginger behaved like hygroscopic non porous solid.

Ramanathan and Rao (1974) recommended the suitable drying temperature of ginger in the range of 60-70^{o}C to get a better quality product and the drying time of about 5-9 h depending on the method of drying.

Pruthi (1980) suggested that, in order to secure large capacity and minimum operating costs of drying ginger, it was essential to use highest temperature that will not materially injure the product. It was also indicated that the optimum drying temperature and the critical temperature of the final product varied with the nature of product and its moisture content.

2.8 Drying methods and equipments

Lee *et al.* (1995) developed an easy to operate, economical, micro computer controlled drying system and applied to the drying of ginger. It was found that temperature, relative humidity and sample weight could be measured and controlled successfully by using the system, which also resulted in improved product quality.

They reported that the optimum drying conditions for ginger were 50°C and 25 per cent RH.

Bhuyan and Prasad (1990) conducted thin layer drying experiments on the Siliguri variety of ginger to study its drying characteristics and evaluated the quality of the dried product by determining its volatile oil and oleoresin content. They also designed a small capacity tray dryer. The evaluation of the dryer showed that the performance was satisfactory at an air temperature of 60°C which was also found to be most suitable temperature for drying ginger slices.

Mantri and Agrawal (1986) developed a multistage dehydration process for ginger and investigated the effect of process parameters such as pre treatments and drying of unpeeled ginger on the quality of the dehydrated product. They observed that the multistage dehydration process reduced the drying time of single stage process and the quality of the dried product was improved or at least maintained. They suggested that ginger may be dried at 85°C up to a moisture content of 50% (wb) during first stage and may be dried at 65°C up to a moisture content of 12% (wb) for reducing drying time and maintaining quality of ginger.

2.9 Quality evaluation/chemical analysis of ginger

Yang *et al.* (2009) conducted an experiment on physical-chemical properties of five types of ginger powders with particles size of 300, 149, 74, 37 and 8.34 lm were investigated. The size was smaller for ginger powders, greater for the surface area (from 0.33-1.32 m^2/g) and bulk density (from 0.30-0.34 g/ml) and smaller for the angle of repose (from 51-46^o) and slide (from 45-39^o). The values of water absorption index (WAI), water solubility index (WSI) and protein content significantly increased with decreasing the size of ginger particles ($p<0.05$). Interestingly, the values of WAI, WSI and protein content of ginger powder with a particle size of 8.34 lm during soaking reached 0.52 g/g, 33.70% and 84.93% for 60 min respectively.

Puengphian & Sirichote (2007) studied on 6-gingerol content and bioactive properties of ginger (*Zingiber officinale Roscoe*) extracts from supercritical CO_2 extraction. Monitoring of 6-gingerol content during drying process, ginger extraction with supercritical CO_2 and bioactive properties analyses of extracts were performed.

Fresh mature ginger rhizomes with 94.17 ± 0.16% moisture content were dried using a rotary air dryer at 55 ± 2^{o}C for 11 h to achieve moisture content of 11.54 ± 0.29%. After drying process, 6-gingerol content of ginger rhizome was reduced from 21.15 ± 0.13 to 18.81 ± 0.15 mg/g dry weight basis. Dried gingers were pulverized to coarse powder approximately 0.5 mm diameter prior to extraction. The supercritical CO_2 extraction of ginger was undertaken with two conditions of 200 bar at 35^{o}C and 230 bar at 40^{o}C. The result showed that the extracts from both conditions; 200 bar at 35^{o}C and 230 bar at 40^{o}C, had 6-gingerol contents of 238.94 ± 0.79 and 170.50 ± 0.45 mg/g extract, total phenolic contents of 183.96 ± 1.25 and 126.04 ± 0.72 mg gallic acid/g extract, respectively. In addition, the ginger extracts showed antioxidant activities using DPPH (1,1-Diphenyl-2-picrylhydrazyl) radical scavenging assay, compared with BHT standard, expressed as EC50, were 13.09 ± 1.77 and 26.68 ± 1.76 μg/ml, respectively. Whereas their antioxidant activities using ABTS (3-ethylbenzothiazoline-6-sulfonic acid) radical cation scavenging assay were 813.33 ± 6.67 and 724.44 ± 7.70 μmol Trolox/g extract, respectively.

Bartley (2006) informed on pungent compound of Australian-grown ginger. The compound was extracted using supercritical CO_2. Methods for analysis of gingerols and shogaols by electrospray - MS have been developed and direct analysis of crude extracts without previous chromatographic separation is shown to be possible by negative ion electrospray - MS. The extracts produced by this procedure are shown to contain about 70 g/kg 6-gingerol and less than 2 g/kg 6-shogaol. The low concentration of shogaols, which are degradation products of gingerols, attests to the mild nature of both the extraction and the analytical procedures.

Sultan *et al.* (2005) evaluated the quality of ginger rhizomes imported from China and Thailand on the basis of their essential oil content and composition. Hydro-distillation yielded 0.98 and 1.58% essential oil (on dry basis) in rhizomes from China and Thailand, respectively. Chemical analysis of essential oil was carried out by GC-FID. Essential oil of Thailand ginger sample contained alpha-pinene (3.59%), alpha-phellandrene (2.84%), myrcene (4.58%), beta-pinene (0.74%), gamma-terpinene (2.49%), 1,8-cineol (3.87%), citral (5.39%) and zingiberene (30.81%). Essential oil of China ginger sample contained alpha-pinene

(0.305%), alpha-phellandrene (1.02%), myrcene (4.82%), gamma-terpinene (2.88%), 1,8-cineol (2.4%), alpha-terpinene (6.5%), citral (4.5%) and zingiberene (8.0%). Ginger sample from Thailand was found to be better in quality due to higher percentage of essential oil (60%).

Tiroutchelvame (2000) studied the effect of drying conditions of ginger and storage methods of ginger on the qualities. They employed solar energy and hot air at temperature 35, 50, 65ºC and investigations of the study indicated that drying of ginger in the sun improved its quality but took longer time than mechanical drying. It is also stated that as hot air temperature was increases browning of ginger slices was also increased.

Yoonhee *et al.* (1995) dried ginger using solar energy and hot air at 35, 50 and 65^{o}C; the absorption of moisture by ginger powder stored at various RH and temperatures was investigated. Drying ginger in the sun improved its qualities but took longer than drying in hot air. As hot-air temperature increased, browning of ginger slices increased. Sun drying was better than hot-air drying by the sensor tests of colour, flavour and taste of ginger powders. Sulphiting ($Na_2S_2O_5$) pretreatment reduces browning and destroys microorganisms in ginger. Storing ginger powder in polyethylene (PE), polypropylene and glass bottles at low and room temperature, moisture content, browning and caking increased with storage time but total sugar content decreased during 10 months storage. Without packaging, moisture content of powders reached equilibrium within a short time at <51% RH and higher temperatures. Powders of higher particle size had higher moisture content. Growth of moulds began in powder at RG >84% and temperatures >25^{o}C. Higher temperatures and RH gave greater browning and caking of ginger powder. Aluminium laminate/PE film was the most effective packaging material for ginger powder. Moisture content was little affected by particle size when powder was stored in 0.08 mm PE film.

Sankari *et al.* (1982) conducted experiments on ginger oil extraction from green ginger and noted that the ginger oil produced from coarsely ground rhizome required long time for distilling by steam distillation process due to the presence of large proportion of sesquiterpenes. They suggested that ginger peelings should also

be distilled to avoid wastage of oil. Their investigation reported that Cochin ginger whole gave 1.9% oil recovery and the peel 0.8% oil.

Rodriguez (1971) examined the colour of dried ginger treated with calcium oxide solution. He applied the process of steeping peeled ginger in plain water for 2 h and then steeping with 1.5-2% calcium oxide (lime) solution for 6 h. He reported that pre-treatment of lime with ginger improved the colour of the dried product.

The literature on osmo-air drying of ginger slices has been found to be scanty. Therefore, the present investigation on osmo-air drying of ginger slices with variation in some important parameters has been planned.

Chapter-III

Materials & Methods

CHAPTER-III

MATERIALS AND METHODS

In this chapter various materials, instruments, equipments, techniques and experimental procedures used to fulfill the objectives of the present investigation have been dealt with. The work was carried out in the Faculty of Agricultural Engineering, I.G.K.V., Raipur (C.G.) in collaboration with the Department of Dairy Chemistry, Department of Dairy Technology, Department of Statistics, Mathematics & Computer Science, I.G.K.V., Raipur (C.G.).

3.1 Materials

Fresh ginger purchased from the local market at Raipur in Chhattisgarh. While purchasing all precautions were taken to select the healthy and well-matured ginger.

Common salt (98% of minimum purity in sodium chloride) purchased from a local store was used as osmotic agent.

3.1.1 Preparation of the samples

Ginger was washed well in water to remove the surface dirt *etc*. Washed ginger were taken out from the water and spread under fan on a paper towel and blotted to remove the surface water. After washing it was peeled off with the help of a stainless steel knife and then based on the preliminary experiments ginger was sliced into 3 ± 0.2 mm thickness (Ramallo and Rodolfo, 2005). The slices so obtained were used immediately for the experiment.

3.1.2 Preparation of osmotic solution

Common salt (98% of minimum purity in sodium chloride) was used as osmotic agent (Mishra, 2007; Bhagyalaxmi, 2006). Salt solutions of different concentrations *viz.* 3%, 6%, 9%, 12% and 15% (w/w) were prepared using distilled water at room temperature.

Trails were taken at salt concentration level of 10, 15, 20, 25 and 30% (w/w) and after conducting a sensory evaluation test, it was found that above 15% of salt concentration levels, the product was not acceptable. So the salt concentration level from 3-15% (w/w) was selected for the present study.

3.1.3 Experimental plan

To meet the proposed research objectives, research outlines stated in Fig. 3.1 was followed in our experimental process.

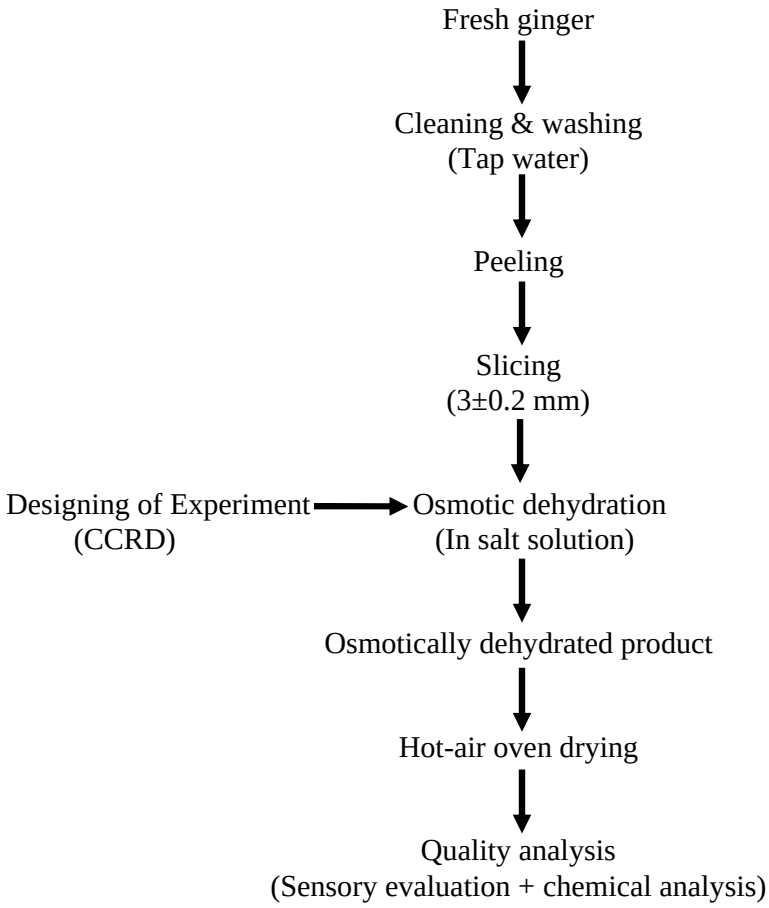

Fig. 3.1 Process flow-chart for the experiment

3.1.4 Experimental procedure

Osmotic dehydration was carried out with commercially available table salt (98% of minimum purity in sodium chloride) as osmotic agent. Five concentration

Fig.3.2: Fresh ginger

Fig.3.3: Ginger slices of 3 ± 0.2 mm thickness

Fig. 3.4: Osmotic dehydration of ginger slices in water bath

Fig.3.5: Hot-air oven drying of ginger slices

levels of salt solution were used in this study to compare the effect of the concentration of the osmotic agents on osmotic dehydration. The salt solution with 3, 6, 9, 12 and 15% (w/w) concentrations were prepared and ginger slices were immersed in the osmotic solution with a sample to osmotic solution mass ratio of 1:5, 1:10, 1:15, 1:20 and 1:25. The temperatures of osmotic solution were 25, 35, 45, 55 and 65ºC. The osmotic dehydration was done for a period of 1, 2.75, 4.5, 6.25 and 8 h. Afterwards, samples were rinsed and wiped again with tissues.

Different concentrations, according to CCRD design, of osmotic solutions were prepared and the solution was mixed with ginger slices in selected mass ratios. The beaker was placed in hot water-bath maintained at desired temperature for soaking. After every 1, 2.75, 4.5, 6.25 and 8 h sample was taken out and moisture content was determined by standard method (Ranganna, 2000). Water loss (%), solid gain (%), weight reduction (%) for each sample was calculated.

3.2 Response surface methodology

3.2.1 Experimental design

The Response Surface Methodology (RSM) was used to estimate the main effects of the process variables on water loss (WL), weight reduction (WR) and solid gain (SG) during the osmotic dehydration of ginger slices. Osmosis temperature (X_1), salt concentration (X_2), mass ratio (X_3) and osmosis treatment time (X_4) were selected as independent variables by means of literature survey and preliminary experiments.

A Central Composite Rotatable Design (CCRD) was used for designing the experimental data. The design included 31 experiments and it is adopted by adding 7 central points and 8 (λ=2) axial points to 2^4 full factorial design (Cochran and Cox, 1994). The center runs provide a means for estimating the experimental error and a measure of lack of fit. The axial points were added to the factorial design to provide for estimation of curvature of the model. Coded values corresponding to the natural values of each variable and CCRD are shown in Table 3.1.

The following second order polynomial model was fitted to the data. Three models of the following form were developed to relate three responses (Y) such as WL, WR and SG to four process variables (X):

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_1 X_1^2 + \beta_2 X_2^2 + \beta_3 X_3^2 + \beta_4 X_4^2 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{44} X_4^2 + \beta_{12} X_1 X_2 + \beta_{23} X_2 X_3 + \beta_{34} X_3 X_4 + \varepsilon$$

Or

$$Y = \beta_0 + \sum_{i=1}^{4} \beta_i X_i + \sum_{i=1}^{4} \beta_{ii} X_i^2 + \sum_{i=1}^{3} \sum_{j=i+1}^{4} \beta_{ij} X_i X_j + \varepsilon$$

Where Y = responses; β_0, β_i, β_{ii} and β_{ij} = constant regression coefficients; X_i, X_j = coded independent variables; ε = experimental error.

3.2.2 Variables and their ranges

In the osmotic dehydration process various factors are involved which directly or indirectly affect the osmosis action. Based on the preliminary experiments the following independent and dependent variables are selected in the present investigation.

The independent variables are:

- Osmosis temperature : 25- 65^{o}C
- Osmosis time : 1-8 h
- Salt concentration : 3-15%
- Mass ratio : 5-25 (w/w)

The dependent variables studied are:

- Water loss
- Solid gain
- Weight reduction

Table 3.1: Central composite rotatable design including coded variables

Std. Run	Factor 1	Factor 2	Factor 3	Factor 4
	Temp. (^{o}C)	Time (h)	Salt Conc. (%)	Mass Ratio (w/w)
1.	35 (-1)	2.75 (-1)	6 (-1)	10 (-1)
2.	55 (1)	2.75 (-1)	6 (-1)	10 (-1)
3.	35 (-1)	6.25 (1)	6 (-1)	10 (-1)
4.	55 (1)	6.25 (1)	6 (-1)	10 (-1)
5.	35 (-1)	2.75 (-1)	12 (1)	10 (-1)
6.	55 (1)	2.75 (-1)	12 (1)	10 (-1)
7.	35 (-1)	6.25 (1)	12 (1)	10 (-1)
8.	55 (1)	6.25 (1)	12 (1)	10 (-1)
9.	35 (-1)	2.75 (-1)	6 (-1)	20 (1)
10.	55 (1)	2.75 (-1)	6 (-1)	20 (1)
11.	35 (-1)	6.25 (1)	6 (-1)	20 (1)
12.	55 (1)	6.25 (1)	6 (-1)	20 (1)
13.	35 (-1)	2.75 (-1)	12 (1)	20 (1)
14.	55 (1)	2.75 (-1)	12 (1)	20 (1)
15.	35 (-1)	6.25 (1)	12 (1)	20 (1)
16.	55 (1)	6.25 (1)	12 (1)	20 (1)
17.	25 (-2)	4.50 (0)	9 (0)	15 (0)
18.	65 (2)	4.50 (0)	9 (0)	15 (0)
19.	45 (0)	1 (-2)	9 (0)	15 (0)
20.	45 (0)	8 (2)	9 (0)	15 (0)
21.	45 (0)	4.5 (0)	3 (-2)	15 (0)
22.	45 (0)	4.5 (0)	15 (2)	15 (0)
23.	45 (0)	4.5 (0)	9 (0)	5 (-2)
24.	45 (0)	4.5 (0)	9 (0)	25 (2)
25.	45 (0)	4.5 (0)	9 (0)	15 (0)
26.	45 (0)	4.5 (0)	9 (0)	15 (0)
27.	45 (0)	4.5 (0)	9 (0)	15 (0)
28.	45 (0)	4.5 (0)	9 (0)	15 (0)
29.	45 (0)	4.5 (0)	9 (0)	15 (0)
30.	45 (0)	4.5 (0)	9 (0)	15 (0)
31.	45 (0)	4.5 (0)	9 (0)	15 (0)

The mathematical models were evaluated for each response by means of multiple linear regression analysis. Modelling was started with a quadratic model including linear, squared and interaction terms. The significant terms in the model were found by analysis of variance (ANOVA) for each response. Significance was judged by determining the probability level that the F-statistic calculated from the data is less than 5%. The model adequacies were checked by prediction error sum of squares (PRESS). A good model will have a low PRESS. Design Expert Ver. 7.1.6 was used to fit response surfaces and to optimize the osmotic dehydration process.

3.2.3 Process optimization

During optimization of osmotic dehydration process several response variables describing the quality characteristics and performs measures of the systems are usually to be optimized. Some of these variables are to be maximized while some are to be minimized. In many cases, these responses are competing, i.e., improving one response may have an opposite effect on another one, which further complicates the situation. Several approaches have been used to handle this problem. One approach uses a constrained optimization procedure, the second is to superimpose the contour diagrams of the different response variables, and the third approach is to solve the problem of multiple responses through the use of a desirability function combining all responses into one measurement.

3.3 Moisture content determination

Moisture content of the sample was determined by standard air oven drying method as described by Ranganna (2000). The procedure is as follows:

1. Weighed sample was kept in a hot air electric oven maintained at 70 ± 2^{o}C for 6 hour.
2. Drawn sample from the oven and cool in desiccator.
3. After cooling weight the sample precisely.
4. The loss in weight was determined and moisture content was calculated.

Calculations:

$$\text{M. C. (\% wb)} = \frac{W_w}{W_i} \times 100$$

$$\text{M.C.}\,(\%\ \text{db}) = \frac{W_w}{W_d} \times 100$$

Where,

W_i = Initial weight of product (g)

W_w = Weight of water removed (g)

W_d = Weight of dry matter (g)

3.4 Measurement of dependent variables

3.4.1 Determination of weight reduction

The weight reduction of ginger slices after osmotic dehydration was calculated using following equation (Moreira and Sereno, 2003):

$$WR = \frac{W_i - W_f}{W_i} \times 100$$

Where,

WR = Weight reduction (%)

W_i = Initial weight of the sample (g)

W_f = Final weight of the sample at time t of osmotic dehydration (g)

3.4.2 Determination of solid gain

The solid gain of ginger slices after osmotic dehydration was calculated using following equation (Moreira and Sereno, 2003):

$$SG = \frac{m_f - m_i}{m_i} \times 100$$

Where,

SG = Solid gain (%)

m_f = solid content after time t of osmotic dehydration (g)

m_i = solid content before osmosis (g)

3.4.3 Determination of water loss

The water loss of ginger slices after osmotic dehydration was calculated using following equation (Moreira and Sereno, 2003):

$$WL = SG + WR$$

Where,

SG = Solid gain (%)
WL = Water loss (%)
WR = Weight reduction (%)

3.5 Hot-air oven drying of ginger slices

The best combination for osmotic dehydration of ginger slices was obtained using the Design Expert 7.1.6 and then after preparing osmotically dehydrated ginger slices it was subjected for the next experiment, i.e., hot air oven drying. A multi rack hot-air oven was used for drying of osmotically dehydrated ginger slices. The cabinet of the oven is made up of GI sheet with thermocol insulation. Ginger slices were dried at three different temperatures, i.e., 40, 50 and 60^{o}C (Yoontte *et al.*, 1995). The air drying characteristics of osmotically dehydrated ginger slices were evaluated under the following parameters.

- Relative humidity (RH)
- Weight of the samples at fixed intervals

Moisture removal of ginger slices were recorded with the help of precise digital electronic balance with least count of 0.1 g**.** Observation of temperature, RH and weight of sample cubes were recorded on observation sheet (Appendix-A).

3.6 Quality analysis

3.6.1 Sensory evaluation

Quality analysis of osmotically dehydrated ginger slices was done according to Ranganna (2000) with 9-point hedonic scale. The average sensory scores for different attributes *viz.* colour, appearance, flavour, texture (mouth feel) and overall

acceptability for ginger slices of thickness size 3 ± 0.2 mm were given. Quality analysis was performed by the panel of semi-trained judges drawn from the employees and students of Faculty of Agricultural Engineering, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.). The panelists were provided the product evaluation sheet (Appendix-B).

Experiment was conducted according to the CCRD and optimized using Design Expert 7.1.6. Best combination for osmotic dehydration of ginger slices was discovered and then quality of the product was evaluated by physico-chemical analysis.

3.6.2 Physico-chemical analysis

3.6.2.1 Determination of fat

The fat content of ginger was estimated by Soxhlet method as given by Ranganna (2000). The procedure is as follows:

1. Take 3 g of dried powdered sample in a thimble and plug the top of the thimble with a wad of fat-free cotton.
2. Drop the thimble into the fat extraction tube of a Soxhlet apparatus.
3. Pour 75 ml anhydrous diethyl ether into the flask.
4. Extract the sample for fat with anhydrous diethyl ether at 40-45^{o}C in Soxhlet's apparatus.
5. Continue the extraction for 6-8 h at a condensation rate of 2-3 drops per second.
6. After extraction, transfer the diethyl ether into beaker.
7. Dry the sample for 30 min. at 100^{o}C.
8. Cool and record the final weight of the fat collected in beaker.

Calculation:

$$\text{Fat}\ (\%) = \frac{W_1 - W_2}{W} \times 100$$

Where,

W_1 = Wt. of beaker containing fat (g)

W_2 = Wt. of empty beaker (g)

W = Wt. of sample taken (g)

3.6.2.2 Determination of protein

Nitrogen content of ginger was determined by Kjeldahl method as given by Ranganna (2000) and protein content was calculated using conversion factor 6.25. The procedure is as follows:

1. Take 0.1-2.0 g of accurately weighed sample in a 500 ml Kjeldahl digestion flask.
2. Add to it 0.5-5.0 g of digestion mixture (K_2SO_4 & $CuSO_4$ in the ratio of 9:1) and 10-30 ml conc. H_2SO_4.
3. Digest sample by heating flask till the sample turns light green or clear and only 2-2.5 ml of the sample is left in the flask.
4. Cool and make the volume to 100 ml by adding distilled water.
5. Take this solution in a distillation flask, add to it 80-85 ml of NaOH solution (40% w/v).
6. Distill and collect the ammonia liberated in 50 ml of boric acid with 2-3 drops of methyl red indicator.
7. Collect approximately 150 ml of the distillate and titrate against with 0.1N HCl or H_2SO_4 till end point appears.

Calculation:

$$\text{Protein (\%)} = \frac{1.4 \times V \times N \times A \times 6.25}{W \times B}$$

Where,

N = Normality of solution (HCl or H_2SO_4)

V = Titer value (ml)

W = Weight of sample taken (g)

A = Volume made up of the digest

B = Aliquot of digest taken (ml)

3.6.2.3 Determination of carbohydrate

The carbohydrate of the sample was measured by Lane & Eynon's method as given by Choudhary (2007). The procedure is as follows:

1. Take 3 g powdered sample in 50 ml distill water.
2. Stir uniformly and keep aside for 1 h with occasional stirring.
3. Filter it and wash the residue with sufficient distill water.
4. Heat the un-dissolved residue for 2.5 h in 100 ml 2.5% HCl solution in a flask equipped with a reflux condenser.
5. Cool, neutralize with NaOH and make up volume of 250 ml & filter it.
6. Fill the filtrate in burette.
7. Take 5 ml each of Fehling A & B solutions in conical flask. Add 20 ml water and bring to boil. Add sugar solution into it from burette until a faint blue colour remains.
8. Add 2-3 drops of methylene blue indicator.
9. Add sugar solution until red colour precipitate of Cu_2O is produced or obtained.
10. Record the volume of sugar solution used for reduction of Fehling solutions.
11. Titrate using standard glucose solution.

Calculation:

$$\text{Carbohydrate (\%)} = \frac{V_3 \times 0.25 \times V_1 \times 0.9}{V_2 \times W}$$

Where,

W = Weight of sample taken (g)

V_1 = Final volume of starch hydrolysate (ml)

V_2 = Volume of standard glucose solution used (ml)

V_3 = Volume of starch hydrolysate used (ml)

3.6.2.4 Determination of volatile oil

The volatile oil content of the dried ginger was determined by distillation method as given by Ranganna (2000). The procedure is as follows:

1. Take 50 g of coarsely ground sample in round bottom flask containing boiling water.
2. Boil the water till the distillation rate of one drop per second was maintained.
3. Continue the distillation process until 2 consecutive readings taken at intervals of 1 h showed no change in the volume of oil in the trap.
4. Cool the set up and allow it to stand until the oil layer was clear.

Calculation:

$$\text{Volatile oil \% (v/w)} = \frac{\text{Volume of oil (ml)}}{\text{Weight of sample (g)}} \times 100$$

3.6.2.5 Determination of texture (hardness)

Hardness is the force required to compress a substance between the molar teeth or between tongue and plate to be given deformation or penetration and designated as soft firm or hard. It is also defined as the maximum load (N) applied to the sample during the first compression.

Hardness measurement of the osmo-air dried ginger slices by probing method was done with the help of texture analyzer. In probing method 3 mm cylinder probe using 5 kg load cell was used. Texture Analyzer (Make: Stable Micro Systems, UK; Model: TA HD Plus) was used for texture analysis. A model of the Texture Analyzer (TA HD Plus) is as shown in Fig. 3.5. Typical settings for measuring the texture are given below:

TA settings:

Pre-Test Speed	:	1.0 mm/s
Test Speed	:	1.0 mm/s
Post-Test Speed	:	10.0 mm/s
Distance	:	3 mm
Trigger type	:	Auto-5g
Force	:	Newton

Fig. 3.6: Texture analysis of osmo-air dried ginger slices by Texture Analyser (TA HD Plus)

Fig.3.7: Colour observation of osmo-air drird ginger using Hunter lab colorimeter (Colour Flex)

Peak load expressed as Newton (force required to puncture the sample) when the 3 mm diameter stainless steel cylinder probe punctured the sample was measured with a computer software program (Texture Exponent 32) attached to the analyser.

3.6.2.6 Determination of colour

The colour of dried ginger slices was analysed using a Hunter Colorimeter. The results were expressed in the Lab colorimetric system, according to the International Commission of Illumination (CIE). In this system, colour was defined conventionally by three numerical parameters. A typical model of the Hunter colour lab is as shown in Fig. 3.6. The ‘L’ value represents lightness, which equals to 0 to black and 100 for white. The ‘a’ represents the amount of red (0 to +60) or green (0 to -60) and ‘b’ represents the amount of yellow (0 to +60) or blue (0 to -60). The software in the computer directly indicated the values. Powder samples of the dried ginger slices were subjected to colour estimation and comparison was made.

Chapter-IV
Results & Discussion

CHAPTER-IV

RESULTS AND DISCUSSION

This chapter deals with the results obtained from different experiments of the present investigation, effect of different independent variables on responses. Efforts have been made to develop three-dimensional graphs to describe the effects of process parameters on responses. The findings have been explained suitably with logical reasons wherever possible. Response surface methodology is an approach used in optimization studies. The findings also have been discussed in the light of theories and with the literature support to the possible extent.

4.1 Osmotic dehydration experiment

The different combinations for osmotic dehydration of ginger slices were formed by using Design Expert 7.1.6. Table 4.1 shows the design in terms of actual factor form and Table 4.2 shows the results of different standard runs of CCRD.

Table 4.1: Central composite rotatable design (actual factor form)

Std. Run	Factor 1	Factor 2	Factor 3	Factor 4
	Temp. (^oC)	Time (h)	Salt Conc. (%)	Mass Ratio (w/w)
1.	35.00	2.75	6.00	10.00
2.	55.00	2.75	6.00	10.00
3.	35.00	6.25	6.00	10.00
4.	55.00	6.25	6.00	10.00
5.	35.00	2.75	12.00	10.00
6.	55.00	2.75	12.00	10.00
7.	35.00	6.25	12.00	10.00
8.	55.00	6.25	12.00	10.00
9.	35.00	2.75	6.00	20.00
10.	55.00	2.75	6.00	20.00
11.	35.00	6.25	6.00	20.00
12.	55.00	6.25	6.00	20.00
13.	35.00	2.75	12.00	20.00
14.	55.00	2.75	12.00	20.00
15.	35.00	6.25	12.00	20.00
16.	55.00	6.25	12.00	20.00
17.	25.00	4.50	9.00	15.00
18.	65.00	4.50	9.00	15.00
19.	45.00	1.00	9.00	15.00
20.	45.00	8.00	9.00	15.00

Std. Run	Factor 1	Factor 2	Factor 3	Factor 4
	Temp. (^oC)	Time (h)	Salt Conc. (%)	Mass Ratio (w/w)
21.	45.00	4.50	3.00	15.00
22.	45.00	4.50	15.00	15.00
23.	45.00	4.50	9.00	5.00
24.	45.00	4.50	9.00	25.00
25.	45.00	4.50	9.00	15.00
26.	45.00	4.50	9.00	15.00
27.	45.00	4.50	9.00	15.00
28.	45.00	4.50	9.00	15.00
29.	45.00	4.50	9.00	15.00
30.	45.00	4.50	9.00	15.00
31.	45.00	4.50	9.00	15.00

Table 4.2: The experimental data of various parameters and their response CCRD arrangement

Std. Run	Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2	Response 3
	Temp. (^oC)	Time (h)	Salt Conc. (%)	Mass Ratio (w/w)	WL (%)	SG (%)	WR (%)
1.	35.00	2.75	6.00	10.00	6.60	1.13	5.47
2.	55.00	2.75	6.00	10.00	8.05	1.38	6.67
3.	35.00	6.25	6.00	10.00	8.53	1.46	7.07
4.	55.00	6.25	6.00	10.00	11.42	1.96	9.47
5.	35.00	2.75	12.00	10.00	7.16	1.23	5.93
6.	55.00	2.75	12.00	10.00	11.26	1.93	9.33
7.	35.00	6.25	12.00	10.00	10.86	1.86	9.00
8.	55.00	6.25	12.00	10.00	16.49	2.83	13.67
9.	35.00	2.75	6.00	20.00	6.76	1.16	5.60
10.	55.00	2.75	6.00	20.00	8.21	1.41	6.80
11.	35.00	6.25	6.00	20.00	8.77	1.50	7.27
12.	55.00	6.25	6.00	20.00	11.58	1.98	9.60
13.	35.00	2.75	12.00	20.00	8.05	1.38	6.67
14.	55.00	2.75	12.00	20.00	11.42	1.96	9.47
15.	35.00	6.25	12.00	20.00	11.18	1.92	9.27
16.	55.00	6.25	12.00	20.00	16.81	2.88	13.93
17.	25.00	4.50	9.00	15.00	2.49	0.43	2.07
18.	65.00	4.50	9.00	15.00	15.12	2.59	12.53
19.	45.00	1.00	9.00	15.00	1.69	0.29	1.40
20.	45.00	8.00	9.00	15.00	14.00	2.40	11.60
21.	45.00	4.50	3.00	15.00	8.21	1.41	6.80
22.	45.00	4.50	15.00	15.00	20.51	3.51	17.00
23.	45.00	4.50	9.00	5.00	13.68	2.34	11.33

Std. Run	Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2	Response 3
	A: Temp. (^oC)	B: Time (h)	C: Salt Conc. (%)	D: Mass Ratio (w/w)	F: WL (%)	G: SG (%)	H: WR (%)
24.	45.00	4.50	9.00	25.00	14.56	2.49	12.07
25.	45.00	4.50	9.00	15.00	14.00	2.40	11.60
26.	45.00	4.50	9.00	15.00	14.16	2.26	11.53
27.	45.00	4.50	9.00	15.00	14.23	2.50	11.47
28.	45.00	4.50	9.00	15.00	13.86	2.37	11.60
29.	45.00	4.50	9.00	15.00	14.32	2.32	11.40
30.	45.00	4.50	9.00	15.00	13.76	2.39	11.53
31.	45.00	4.50	9.00	15.00	14.72	2.43	11.60

4.1.1 Water loss

The kinetics of water loss at different process conditions was obtained. The values of water loss for the different standard runs of experiments are presented in Table 4.2. It can be observed from results, Table 4.2, that the water loss varied from 1.69-20.51%. To visualize the combine effect of independent variables *viz.* time, temperature, salt concentration of osmotic solution and mass ratio on water loss, the response surface and contour plots were generated (Fig 4.1 a, b, c and d).

It can be depicted from the figure that with the increase in the time, salt concentration of osmotic solution and temperature the loss of water or the removal of water increased. Water loss is not much affected by mass ratio (product to osmotic solution). Slight increase of water loss is observed with the increase of mass ratio. The maximum water loss was 20.51% found for sample osmotically dehydrated at 45^{o}C for 4.5 h at 1:15 product to osmotic solution of 15% salt concentration. The minimum 1.69% water loss was found for samples osmotically dehydrated at 45^{o}C for 1 h at 1:15 product to osmotic solution of 9% salt concentration (Table 4.2). This suggests that at higher concentration of osmotic solution, temperature and time is responsible for increasing the water loss.

It can further be seen that water loss effect was more pronounced when the salt concentration level exceeds beyond 6%. The effect of dehydration time on water loss indicates that as the time increases the water loss increases which were obvious. This was true for all the combination of salt concentration and temperature set.

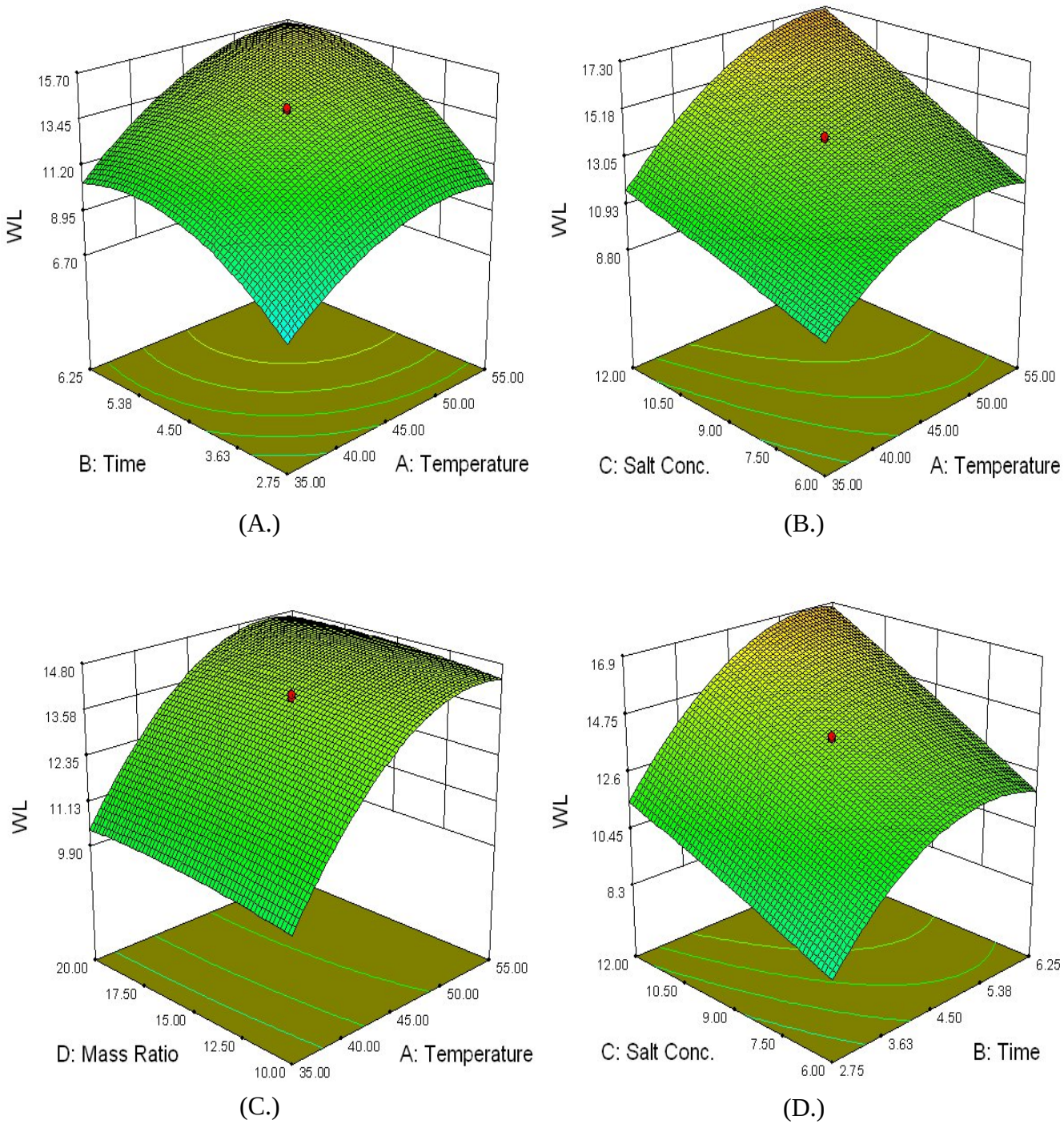

Fig. 4.1: Water loss (%) as a function of **A.** Processing time (h) and temperature (^{o}C) **B.** Salt concentration (%) and temperature (^{o}C) **C.** Mass ratio (w/w) and temperature (^{o}C) **D.** Salt concentration (%) and time (h).

At the beginning of the process, because of the high osmotic driving force between the concentrated solution and the fresh sample, the rate of water removal or water loss was relatively high. Increasing temperature with processing time and salt concentration rises up water loss rapidly. Especially, higher process temperatures and salt concentration seem to promote faster water loss. Rapid removal of water in the early stages of osmotic dehydration has been reported by several researchers (Ertekin & Akaloz, 1996; Nieto *et al.,* 2004; Lazarides *et al.,* 1995; Lewicki & Lenart, 1995; Shi & Le Maguer, 2002).

At short processing times, increasing temperature and salt concentration raises water loss. This phenomenon is attributed to the diffusional differences between water and solutes as related to their molar masses (Lazarides et al., 1995; Raoult-Wack et al., 1991; Torregiani, 1993). However, towards equilibrium end point, water loss, solid gain and weight reduction was not affected significantly by the temperature, time and salt concentration.

Although water loss reached nearly the equilibrium conditions towards the processing times 5-5.5 h. This is due to solid gain. Increase in solid gain blocks the surface layers of the product, which reduces the concentration gradient between the product and osmotic solution, posing an additi**o**nal resistance to mass exchange and lowering the rates of water loss at further processing times (Fig. 4.1 a).

On the other hand the analysis of variance was calculated for fitting the second order polynomial model to experimental data. It can be seen that the regression models were found to be statistically significant. Statistical significance of all main effects, linear, quadratic, and interaction of effects calculated for response (water loss) can also be shown in Table 4.3. Further, the ANOVA revealed that temperature, time and concentration of osmotic solution have significant effect on water loss of osmotically dehydrated ginger slices. Predicted residual sum of squares (PRESS) value was also calculated to check the model adequacy.

Table 4.3: ANOVA table for response surface quadratic model of water loss

Source	Sum of Squares	df	Mean Square	F- value	p-value Prob>F	
Model	480.81	14	34.34	13.23	< 0.0001	Significant
A-Temperature	115.35	1	115.35	44.45	< 0.0001	
B-Time	116.05	1	116.05	44.72	< 0.0001	
C-Salt Conc.	95.79	1	95.79	36.91	< 0.0001	
D-Mass Ratio	0.73	1	0.73	0.28	0.6033	
AB	2.72	1	2.72	1.05	0.3212	
AC	6.42	1	6.42	2.47	0.1353	
AD	0.04	1	0.04	0.02	0.9022	
BC	2.85	1	2.85	1.10	0.3099	
BD	0.01	1	0.01	0.00	0.9608	
CD	0.06	1	0.06	0.02	0.8828	
A^2	65.73	1	65.73	25.33	0.0001	
B^2	88.32	1	88.32	34.03	< 0.0001	
C^2	0.47	1	0.47	0.18	0.6757	
D^2	1.02	1	1.02	0.39	0.5399	
Residual	41.52	16	2.60			
Lack of Fit	40.90	10	4.09	39.62	0.0001	
Pure Error	0.62	6	0.10			
Total	522.34	30				

PRESS = 236.45

Multiple linear regression analysis of the experimental data yielded second order polynomial models for predicting water loss, as assumed at the beginning of the study.

4.1.1.1 Final equation in terms of actual factors

- $Y_1 = -36.77 + 1.3\ X_1 + 4.6\ X_4 - 0.45\ X_2 + 0.28\ X_3 + 0.02\ X_1X_4 + 0.02\ X_1X_2 - 1x10^{-3}\ X_1X_3 + 0.08\ X_4X_2 - 2.29x10^{-3}\ X_4X_3 + 4x10^{-3}\ X_2X_3 - 0.01\ (X_1)^2 - 0.5\ (X_4)^2 - 0.01\ (X_2)^2 - 7.5x10^{-3}\ (X_3)^2$

  After neglecting the non-significant terms the final equation:

- $Y_1 = -36.77 + 1.3\ X_1 + 4.6\ X_4 - 0.45\ X_2 - 0.01\ (X_1)^2 - 0.5\ (X_4)^2$

Where,

Y_1= Water loss, X_1 = Osmosis temperature, X_2 = Salt concentration, X_3 = Mass ratio, X_4 = Osmosis treatment time, x = multiplication

4.1.2 Solid gain

The solid gain of ginger slices was calculated during osmotic dehydration experiment for each after 1, 2.75, 4.5, 6.25 and 8 h according to CCRD combinations. The values of solid gain for the different standard runs of experiments are presented in Table 4.2. It can be observed from results, Table 4.2, that the solid gain varied from 0.29-3.51%. To visualize the combine effect of independent variables *viz.* time, temperature, salt concentration of osmotic solution and mass ratio on solid gain, the response surface and contour plots were generated (Fig 4.2 a, b, c and d).

It can be observed from the figure that with the increase in the time, salt concentration of osmotic solution and temperature the solid gain increased. Solid gain is not much affected by mass ratio (product to osmotic solution). Slight increase of solid gain is observed with the increase of mass ratio. The maximum solid gain was 3.51% found for sample osmotically dehydrated at 45^{o}C for 4.5 h at 1:15 product to osmotic solution of 15% salt concentration. The minimum 0.29% solid gain was found for samples osmotically dehydrated at 45^{o}C for 1 h at 1:15 product to osmotic solution of 9% salt concentration (Table 4.2). This suggests that at higher concentration of osmotic solution, temperature and time is responsible for increasing the solid gain.

It can further be seen that solid gain effect was more pronounced when the salt concentration level exceeds beyond 6%. The effect of dehydration time on solid gain indicates that as the time increases the solid gain increases which were obvious. This was true for all the combination of salt concentration and temperature set. Higher process temperatures and salt concentration seem to promote faster solid gain. At short processing times, increasing temperature and salt concentration raises solid gain.

At all processing time the solid gain increases gradually with salt concentration, time and temperature. The increase in solid gain is higher at high temperatures (50-55^{o}C) like water loss and weight reduction. The effect of salt concentration on solid gain is greater. This can be explained by the ionization characteristics and low molecular weight of salt, which makes it easily diffuse into the product and increases the driving force for dehydration.

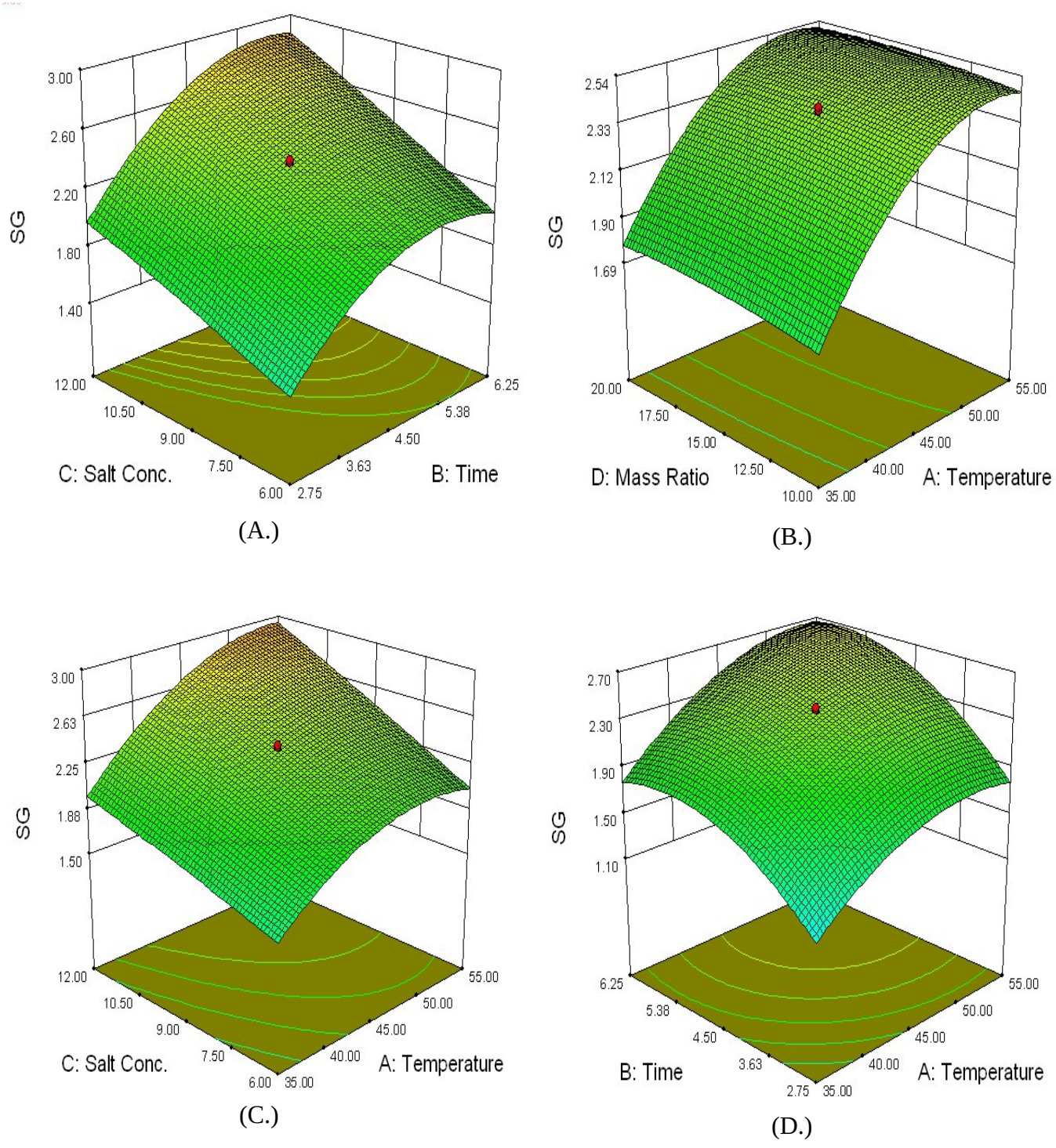

Fig. 4.2: Solid gain (%) as a function of **A.** Salt concentration (%) and time (h) **B.** Mass ratio (w/w) and temperature (^{o}C) **C.** Salt concentration (%) and temperature (^{o}C) **D.** Time (h) and temperature (^{o}C).

Although solid gain reached nearly the equilibrium conditions towards the processing times 5-5.5 h. Increase in solid gain blocks the surface layers of the product, which reduces the concentration gradient between the product and osmotic solution, posing an additi**o**nal resistance to mass exchange at further processing times (Fig. 4.2 d).

On the other hand the analysis of variance was calculated for fitting the second order polynomial model to experimental data. It can be seen that the regression models were found to be statistically significant. Statistical significance of all main effects, linear, quadratic, and interaction of effects calculated for response (solid gain) can also be shown in Table 4.4. Further, the ANOVA revealed that temperature, time and concentration of osmotic solution have significant effect on solid gain of osmotically dehydrated ginger slices. Predicted residual sum of squares (PRESS) value was also calculated to check the model adequacy.

Table 4.4: ANOVA table for response surface quadratic model of solid gain

Source	**Sum of Squares**	**df**	**Mean Square**	**F- value**	**p-value Prob>F**	
Model	13.84	14	0.99	12.79	< 0.0001	Significant
A-Temperature	3.39	1	3.39	43.83	< 0.0001	
B-Time	3.41	1	3.41	44.09	< 0.0001	
C-Salt Conc.	2.81	1	2.81	36.40	< 0.0001	
D-Mass Ratio	0.02	1	0.02	0.28	0.6058	
AB	0.08	1	0.08	1.03	0.3245	
AC	0.19	1	0.19	2.44	0.1378	
AD	0.00	1	0.00	0.02	0.9029	
BC	0.08	1	0.08	1.08	0.3132	
BD	0.00	1	0.00	0.00	0.9611	
CD	0.00	1	0.00	0.02	0.8836	
A^2	1.77	1	1.77	22.94	0.0002	
B^2	2.41	1	2.41	31.20	< 0.0001	
C^2	0.00	1	0.00	0.05	0.8320	
D^2	0.01	1	0.01	0.17	0.6840	
Residual	1.24	16	0.08			
Lack of Fit	1.20	10	0.12	20.33	0.0008	
Pure Error	0.04	6	0.01			
Total	15.07	30				

PRESS = 6.96

Multiple linear regression analysis of the experimental data yielded second order polynomial models for predicting water loss, as assumed at the beginning of the study.

4.1.2.1 Final equation in terms of actual factors

- $Y_2 = -5.85 + 0.2\ X_1 + 0.7\ X_4 - 0.09\ X_2 + 0.03\ X_3 + 4x10^{-3}\ X_1X_4 + 3.6x10^{-3}\ X_1X_2 - 1.7x10^{-4}\ X_1X_3 + 0.01\ X_4X_2 - 3.9x10^{-4}\ X_4X_3 + 6.8x10^{-4}\ X_2X_3 - 2.4x10^{-3}\ (X_1)^2 - 0.09\ (X_4)^2 - 1.2x10^{-3}\ (X_2)^2 - 8.6x10^{-4}\ (X_3)^2$

  After neglecting the non-significant terms the final equation:

- $Y_2 = -5.85 + 0.2\ X_1 + 0.7\ X_4 - 0.09\ X_2 - 2.4x10^{-3}\ (X_1)^2 - 0.09\ (X_4)^2$

Where,

Y_2 = Solid gain, X_1 = Osmosis temperature, X_2 = Salt concentration, X_3 = Mass ratio, X_4 = Osmosis treatment time, x = multiplication

4.1.3 Weight reduction

The weight reduction of ginger slices was calculated during osmotic dehydration experiment for each after 1, 2.75, 4.5, 6.25 and 8 h according to CCRD combinations. The values of weight reduction for the different standard runs of experiments are presented in Table 4.2. It can be observed from results, Table 4.2, that the weight reduction varied from 1.40-17.0%. To visualize the combine effect of independent variables *viz.* time, temperature, salt concentration of osmotic solution and mass ratio on weight reduction, the response surface and contour plots were generated (Fig 4.3 a, b, c and d).

It can be seen from the figure that with the increase in the time, salt concentration of osmotic solution and temperature the weight reduction increased. Weight reduction is not much affected by mass ratio (osmotic solution to product). Slight increase of weight reduction is observed with the increase of mass ratio. The maximum weight reduction was 17.0% found for sample osmotically dehydrated at 45^{o}C for 4.5 h at 1:15 product to osmotic solution of 15% salt concentration. The minimum 1.40% weight reduction was found for samples osmotically dehydrated at 45^{o}C for 1 h at 1:15 product to osmotic solution of 9% salt concentration (Table 4.2). This suggests that at higher concentration of osmotic solution, temperature and time is responsible for increasing the weight reduction.

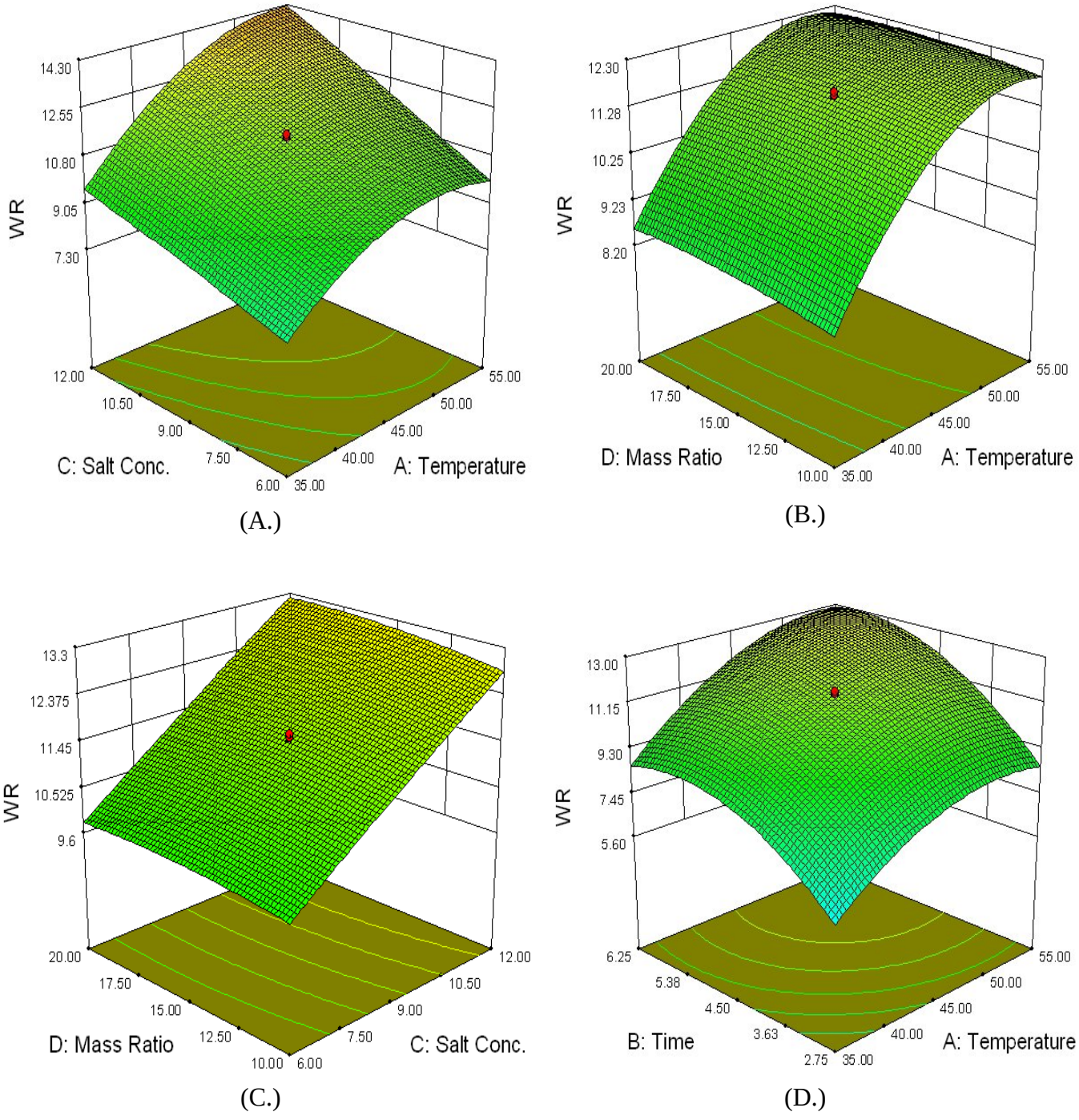

Fig. 4.3: Weight reduction (%) as a function of **A.** Salt concentration (%) and temperature (^{o}C) **B.** Mass ratio (w/w) and temperature (^{o}C) **C.** Mass ratio (w/w) and salt concentration (%) **D.** Time (h) and temperature (^{o}C).

It can further be seen that weight reduction effect was more pronounced when the salt concentration level exceeds beyond 6%. The effect of dehydration time on weight reduction indicates that as the time increases the weight reduction increases which were obvious. This was true for all the combination of salt concentration and temperature set. Higher process temperatures and salt concentration seem to promote faster weight reduction.

At all processing time the weight reduction increases rapidly with salt concentration, time and temperature. The increase in weight reduction is higher at high temperatures (50-55^{o}C) like water loss. The effect of salt concentration on weight reduction is greater. This can be explained by the ionization characteristics and low molecular weight of salt which makes it easily diffuse into the product and increases the driving force for dehydration. Although weight reduction reached nearly the equilibrium conditions towards the processing times 5-5.5 h.

The effect of temperature can be seen obviously at high salt concentrations (Fig. 4.3 a). Chenlo *et al.* (2002); Moreira *et al.* (2003) explained this effect as increasing temperature gives better water transfer and weight reduction characteristics on the product surface due to lower viscosity of the osmotic medium. Similar results have been reported by a vast number of researchers for different products (Collignan & Raoult-Wack, 1994; Giempero *et al.*, 2001; Sacchetti *et al.*, 2001; Sereno *et al.*, 2001).

On the other hand the analysis of variance was calculated for fitting the second order polynomial model to experimental data. It can be seen that the regression models were found to be statistically significant. Statistical significance of all main effects, linear, quadratic, and interaction of effects calculated for response (weight reduction) can also be shown in Table 4.5. Further, the ANOVA revealed that temperature, time and concentration of osmotic solution have significant effect on weight reduction of osmotically dehydrated ginger slices. Predicted residual sum of squares (PRESS) value was also calculated to check the model adequacy.

Table 4.5: ANOVA table for response surface quadratic model of weight reduction

Source	Sum of Squares	df	Mean Square	F- value	p-value Prob>F	
Model	324.17	14	23.16	13.17	< 0.0001	Significant
A-Temperature	79.21	1	79.21	45.06	< 0.0001	
B-Time	79.69	1	79.69	45.34	< 0.0001	
C-Salt Conc.	65.78	1	65.78	37.42	< 0.0001	
D-Mass Ratio	0.50	1	0.50	0.28	0.6009	
AB	1.87	1	1.87	1.06	0.3179	
AC	4.41	1	4.41	2.51	0.1328	
AD	0.03	1	0.03	0.02	0.9015	
BC	1.96	1	1.96	1.12	0.3067	
BD	0.00	1	0.00	0.00	0.9605	
CD	0.04	1	0.04	0.02	0.8820	
A^2	41.75	1	41.75	23.75	0.0002	
B^2	56.72	1	56.72	32.27	< 0.0001	
C^2	0.10	1	0.10	0.06	0.8170	
D^2	0.34	1	0.34	0.19	0.6680	
Residual	28.12	16	1.76			
Lack of Fit	28.09	10	2.81	473.98	< 0.0001	
Pure Error	0.04	6	0.01			
Total	352.30	30				

PRESS = 161.83

Multiple linear regression analysis of the experimental data yielded second order polynomial models for predicting water loss, as assumed at the beginning of the study.

4.1.3.1 Final equation in terms of actual factors

- $Y_3 = -28.5 + 1.03\ X_1 + 3.7\ X_4 - 0.4\ X_2 + 0.17\ X_3 + 0.01\ X_1X_4 + 0.01\ X_1X_2 - 8.3x10^{-4}\ X_1X_3 + 0.06\ X_4X_2 - 1.9x10^{-3}\ X_4X_3 + 3.3x10^{-3}\ X_2X_3 - 0.01\ (X_1)^2 - 0.45\ (X_4)^2 - 6.4x10^{-3}\ (X_2)^2 - 4.3x10^{-3}\ (X_3)^2$

After neglecting the non-significant terms the final equation:

- $Y_3 = -28.5 + 1.03\ X_1 + 3.7\ X_4 - 0.4\ X_2 - 0.01\ (X_1)^2 - 0.45\ (X_4)^2$

Where,

Y_3 = Weight reduction, X_1 = Osmosis temperature, X_2 = Salt concentration, X_3 = Mass ratio, X_4 = Osmosis treatment time, x = multiplication

4.2 Process optimization of osmotic dehydration

Optimum condition for osmotic dehydration of ginger slices were determined to obtain maximum water loss, weight reduction and minimum solid gain (Eren and Figen, 2007). Second order polynomial models obtained in this study were utilized for each response in order to determine the specified optimum conditions. These regression models are valid only in the selected experimental domain.

In this investigation temperature, processing time, salt concentration and mass ratio were selected in the range of 25-65^{o}C, 1-8 h, 3-15% and 5-25 (w/w) respectively. By applying desirability function method, two solutions were obtained for the optimum covering the criteria. The first one is 45.38^{o}C for temperature, 4.58 h for time, 9.16% for salt concentration and 15.02 for mass ratio. The second one is 45.53^{o}C for temperature, 4.58 h for time, 9.13% for salt concentration and 15.06 for mass ratio Table 4.6. Also, desirability value of the first solutions is greater than second one. So, the factor level combinations obtained at the first solution were selected as the optimum. At this point water loss, solid gain and weight reduction were calculated as 14.44, 2.43 and 11.77% respectively.

Table 4.6: Result of optimization by desirability function

No.	Temp. (^{o}C)	Time (h)	Salt Conc. (%)	Mass Ratio (w/w)	WL (%)	SG (%)	WR (%)	Desirability	
1.	45.38	4.58	9.16	15.02	14.44	2.43	11.77	0.53	Selected
2.	45.53	4.58	9.13	15.06	14.42	2.41	11.75	0.52	

4.3 Air drying characteristics of osmotically dehydrated ginger slices

The air drying behaviour of ginger slices were analysed by a multi rack hot-air oven dryer. Ginger contains about 80% water, 1.2% fat, 12.30% carbohydrates, 2.30% proteins and 1.4% volatile oil. The air drying characteristic of ginger slices varies fairly for different temperature.

During the process of drying of 3-5.5 h for osmotically dehydrated ginger slices, the air temperature inside the oven is maintained from 40-60^{o}C. The relative humidity of the air inside the chamber was measured in the decreasing range of 40-17%. The RH increase initially for 0.5 h of drying and after that it reduces with

higher drying period. The observations made during the process of drying for different samples at 40, 50 and 60°C were recorded using Appendix A.

The drying behavior of ginger slices of different temperature levels of 40, 50 and 60°C for hot-air oven drying is presented in Fig 4.4 as a plot of moisture content *versus* drying time.

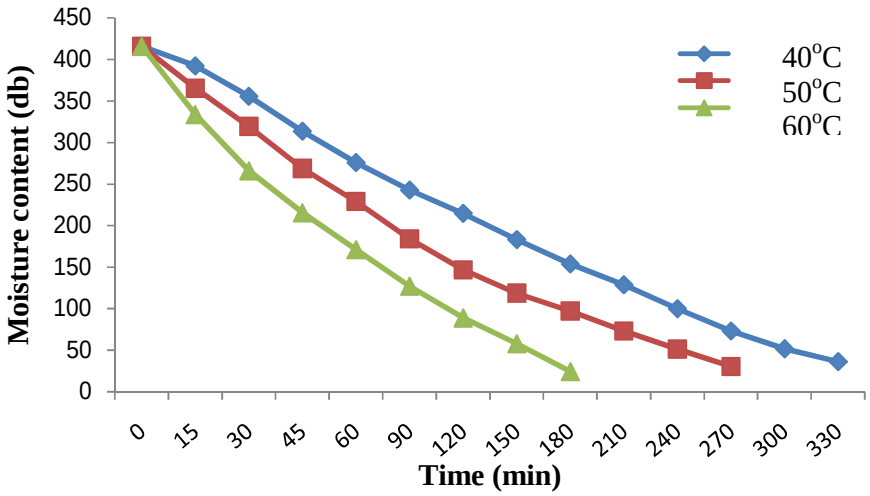

Fig. 4.4: Change in moisture content with respect to time at 40, 50 and 60°C

Data were analyzed. The best fit equations for each combination was determined and given in Fig. 4.5-4.7. It appears from these relationships that there was significant rate of reduction in moisture content with respect to time in all the combinations as the correlation coefficient, R^2, value were above 0.7 in all the equations.

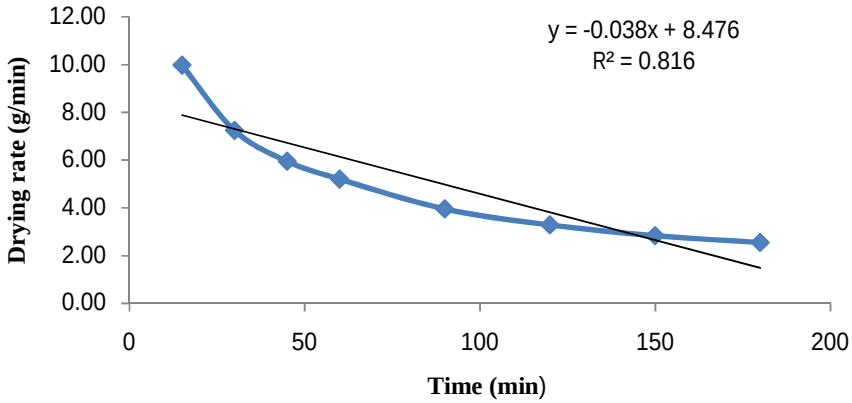

Fig. 4.5: Drying rate curve of ginger slices at 60°C

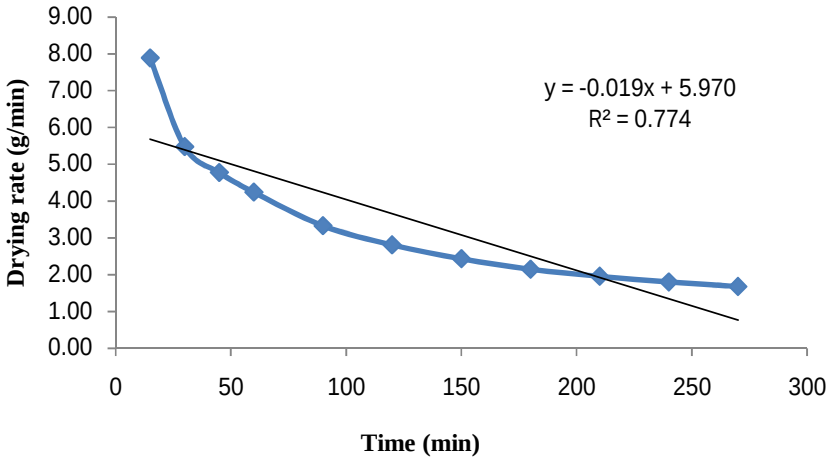

Fig. 4.6: Drying rate curve of ginger slices at 50^{o}C

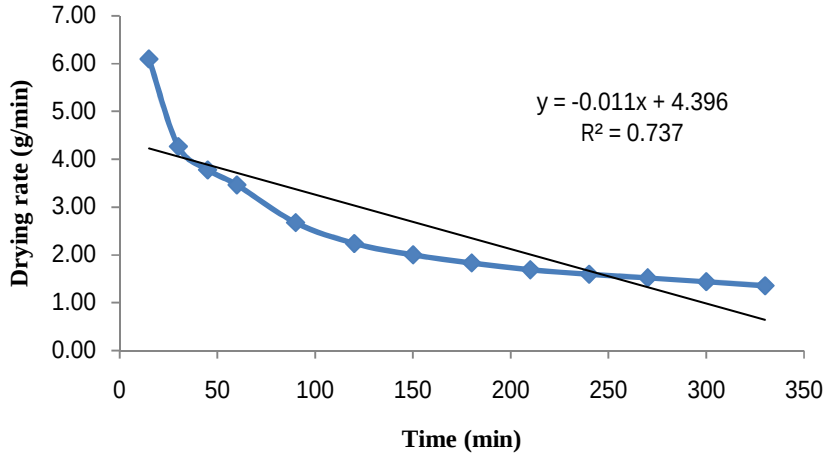

Fig. 4.7: Drying rate curve of ginger slices at 40^{o}C

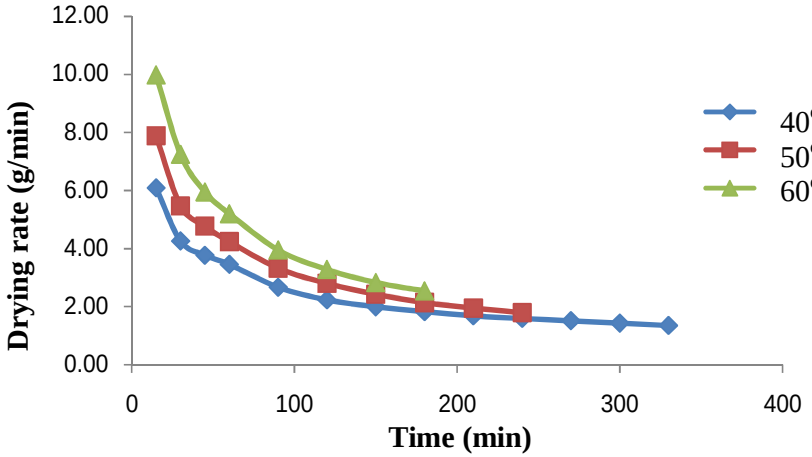

Fig. 4.8: Change in drying rate with respect to time

The effects of drying time on moisture removal of sample were higher at initial period of 1 h in all treatment and it lowers for higher drying time. Not much variation was observed in the drying behavior of ginger slices however the final moisture content of the samples was differed slightly and was in the range of 4.2-6.2% (wb) after drying.

It can be depicted from the Fig. 4.8 that the ginger slices drying process did not have a constant rate drying period and that in falling rate drying period ginger slices behaved like hygroscopic non porous solid. It took about 5.5 h to reduce the moisture content from 71.27-6.27% (wb) from the ginger slices in drying at 40^{o}C. On increasing the temperature the drying time was reduced. The moisture content varies form 71.27-5.20% (wb) at 50^{o}C, drying time was 4.5 h and 71.27-4.20% (wb) at 60^{o}C with drying time of 3 h. Fig. 4.9 shows the osmo-air dried ginger slices.

Fig. 4.9: Osmo-air dried ginger slices

4.4 Quality analysis

4.4.1 Sensory evaluation

As described in the methodology osmotic dehydration experiment of ginger slices was conducted at five different salt concentration levels, i. e., 3, 6, 9, 12 and 15% (w/w). So in order to check the acceptability and quality of ginger slices sensory evaluation test was conducted.

Sensory analysis of osmo-air dried ginger slices was done according to Ranganna (2000) with 9-point hedonic scale. Samples were coded according to salt concentration level. The average sensory scores for different attributes *viz.* colour, appearance, flavour, taste, texture (mouth feel) and overall acceptability for ginger slices of thickness size 3 ± 0.2 mm were given. Samples were subjected to sensory evaluation to get an idea about the liking/disliking samples by the panelist. Sensory evaluation was performed in accordance with the 9-point hedonic scale (Appendix-B).

The overall sensory qualities of osmo-air dried ginger slices were judged by a panel of 11 judges. The average score of sensory evaluation test is given in the Table 4.7. It can be seen that average score obtained by each attribute is either 7 or above, this indicates that the sample was liked moderate or liked very much in respective attributes by the judges Table 4.7. The average score shows that the overall acceptability was higher for the sample no. 3 (9% salt concentration level).

Table 4.7 Average scores for different sensory attributes of osmo-air dried ginger slices

Sample No.	Colour	Appearance	Flavour	Taste	Texture (Mouth Feel)	Overall Acceptability
1.	7.00	6.64	7.27	7.00	7.09	7.18
2.	7.18	7.09	7.36	7.45	6.91	7.25
3.	7.45	7.64	7.82	7.82	7.64	7.73
4.	6.91	6.73	7.73	7.64	7.55	7.39
5.	7.64	7.55	7.36	7.73	7.36	7.55

Sample 1 = 3% salt concentration level
Sample 2 = 6% salt concentration level
Sample 3 = 9% salt concentration level
Sample 4 = 12% salt concentration level
Sample 5 = 15% salt concentration level

4.4.2 Physico-chemical analysis

Osmotically dehydrated ginger slices was dried at three different temperature *viz.* 40, 50 and 60^{o}C and then quality of osmo-air dried ginger slices was evaluated on the basis of physico-chemical analysis (Table 4.8).

Table 4.8: Physico-chemical analysis of osmotically dehydrated ginger dried at different temperature level

Parameters	40°C	50°C	60°C
Moisture	6.2%	5.4%	4.2%
Fat	6.3%	6.28%	6.3%
Protein	8.48%	8.5%	8.52%
Carbohydrate	66.3%	66.5%	66.1%
Volatile oil	1.34%	1.25%	1.23%
Colour (L, a, b)	69.94, 4.72, 34.49	70.33, 4.68, 34.40	69.30, 4.87, 34.01
Texture (Hardness)	6.12 N	6.5 N	6.9 N

It is observed from the result that moisture content were in the range of 4.2-6.2% (wb), fat 6.28-6.3%, protein 8.48-8.52%, carbohydrate 66.1-66.5%, volatile oil 1.23-1.34% and texture (hardness) 6.12-6.9 N. In a similar study by Pruthi *et al.* (1993) reveals that fat content of solar dried ginger was 6.4%, protein 8.6%, carbohydrate 66.50%, volatile oil 1.4%.

Chapter-V
Summary & Conclusions

CHAPTER-V

SUMMARY AND CONCLUSIONS

Spices and condiments play an important role in human diet and nutrition. They are indispensable sources of essential dietary nutrients and vitamins besides providing medicinal value. They provide colour, flavor and variety to the other monotonous diet. Ginger is one of the spice and is very important from therapeutic, nutritional and medicinal point of view. Due to high moisture content (above 80%), it is perishable. The quality of ginger can be improved and shelf life be enhanced by converting them into quality products through processing. Quality processed products have high consumer value in national and international market.

A major goal of food processing is to convert such perishable commodities into stable products that can be stored for extended periods thereby reducing losses and making them available in off seasons and at a place for away from the site of production. Osmo-air drying is one of the best way for preservation of food products. The present study was conducted to study the influence of osmo-air drying of ginger slices. The objectives of this investigation were:

1. To study the osmotic dehydration characteristics of ginger slices.
2. To study the air drying characteristics of osmotically dehydrated ginger slices.
3. To evaluate the quality of dried ginger slices.

5.1 Summary

The work was carried out in the Faculty of Agricultural Engineering, I.G.K.V., Raipur (C.G.) in collaboration with the Department of Dairy Chemistry, Department of Dairy Technology, Department of Statistics, Mathematics & Computer Science, I.G.K.V., Raipur (C.G.).

The analysis of the observations was done as per the methods described in the methodology. Presentation of data and results has been done logically with suitable tables and graphs. Inferences have been drawn and suitable explanations have been presented as far as possible.

Gingers were washed well in running water to remove the surface dirt *etc*. The fruits were then peeled off with the help of a stainless steel knife. After peeling it was then sliced out using a slicer in 3 ± 0.2 mm slices. Five concentration levels of salt solution were used in this investigation to compare the effect of the concentration of the osmotic agents on osmotic dehydration. The salt solution with 3, 6, 9, 12 and 15% (w/w) concentrations were prepared. Ginger slices were immersed in the osmotic reagents with a fruit to osmotic solution mass ratio of 1:5, 1:10, 1:15, 1:20 and 1:25. Soaking experiments were conducted at ambient condition at 25, 35, 45, 55 and 65^{o}C in beakers using water bath. The osmotic dehydration was done for a period of 1, 2.75, 4.5, 6.25 and 8 h according to the central composite rotatable design, formed by the Design Expert 7.1.6 software. The dependent variables studied were water loss, weight reduction and solid gain after dehydration. The results are summarized as under:

1. Moisture content of the sample was determined by standard air oven method (Ranganna, 2000) and it was found that the initial moisture content of ginger slices was 82.8% (wb).
2. The osmotic dehydration process of ginger slices was optimized by desirability function using Design Expert 7.1.6 software and the result of optimization is 45.3^{o}C for temperature, 4.58 h for time, 9.16% for salt concentration and 15.02 for mass ratio at this point water loss, solid gain and weight reduction were calculated as 14.4, 2.4 and 11.7% respectively.
3. After optimization the osmo-air dried ginger slices was prepared according to the optimized combination and then air drying characteristics of ginger slices are determined by hot-air oven at different temperature (40, 50 and 60^{o}C).
4. Moisture content of osmo-air dried ginger slices were in the range of 4.2-6.2% (wb).
5. Quality analysis of osmo-air dried ginger slices was done according to Ranganna (2000) with 9-point hedonic scale. The nine point hedonic scale was used to describe the colour, acceptance, taste, flavour, texture, overall acceptability.
6. Sensory evaluation revealed that the product, which was osmotically dehydrated at 9% salt concentration was more acceptable than others.

7. After examining the osmo-air dried ginger slices by the sensory evaluation test, physico-chemical analysis of ginger slices were conducted.
8. It was found that osmo-air dried ginger contains about fat 6.28-6.3%, protein 8.48-8.52%, carbohydrate 66.1-66.5%, volatile oil 1.23-1.34% while texture (hardness) 6.12-6.9 N, colour L, a, b was 69.30-70.33, 4.68-4.87 and 34.01-34.59 respectively.

5.2 Conclusions

Response Surface Method was used to determine the optimum operating conditions that yield maximum water loss, weight reduction and minimum solid gain in osmotically dehydrated ginger slices. Osmotic dehydration process was optimized by desirability function. Further hot-air oven drying and quality evaluation tests were conducted. From the present investigation the following conclusions have been drawn:

1. Osmotically dehydrated ginger slices above 15% salt concentration were not acceptable.
2. At the beginning of the process, because of the high osmotic driving force between the concentrated solution and the fresh sample, the rate of water removal or water loss was relatively high.
3. At short processing times, increasing temperature and salt concentration raises water loss, solid gain and weight reduction.
4. Water loss and weight reduction reached nearly the equilibrium conditions towards the processing times 5-5.5 h. This is due to solid gain. Increase in solid gain blocks the surface layers of the product, which reduces the concentration gradient between the product and osmotic solution, posing an additi**o**nal resistance to mass exchange and lowering the rates of water loss and weight reduction at further processing time.
5. Slight increase of water loss, solid gain and weight reduction was occurred with the increase of mass ratio (product to osmotic solution).
6. Analysis of variance has shown that the effects of the process variables including temperature, time and salt concentration were statistically significant while mass ratio was not statistically significant.

7. The drying rate curves indicated that ginger slices drying process did not have a constant rate drying period.
8. The texture (hardness) of the ginger slices were much affected by the size, shape, moisture content and thickness.

5.3 Suggestions for future research work

1. Determination of osmotic dehydration characteristics of ginger slices at various thickness sizes.
2. Rehydration characteristics of osmotically dehydrated ginger slices should be evaluated.
3. Other drying methods like open sun drying, solar drying and indirect drying and vacuum drying should be performed.

References

RERERENCES

Alves, S. M. and Silveira, M. 2002. Drying of osmotically dehydrated tomatoes. *Journal of Food Science and Technology,* **21**: 1121-1130.

Andrzej, L. 1991. Effect of saccarose on water sorption and rehydration of dried carrot. *Revista Ciencia Agronomica*, **91**: 489-498.

AOAC. 1980. Association of Official Analytical Chemist Official Methods of Analysis. Washington, DC.

Aniko, M. and Peter, M. 2002. Modelling of sugar transfer during osmotic dehydration of carrots. Periodica Polytechnica. *Jounal of Food Science and Technology,* **46** (2): 83-92.

Aves, M. and Wang, R. 2005. Osmotic dehydration of acerola fruit. *Journal of Food Science and Technology*, **8** (4): 97-101.

Bawa, A. S. and Gujral, H. S. 2000. Effect of osmotic agents on the drying behaviour and product quality in raisin processing. *Journal of Scientific and Industrial Research,* **59** (1): 63-66.

Bartley, John P. 2006. A new method for the determination of pungent compounds in ginger (*Zingiber officinale*). *Journal of Food Medicine,* **8** (2):125-32.

Bellmawr, S., Lei, B., Poirier, C. 2004. Effect of osmo-air drying on watermelon product. *Journal of Food Science and Technology*, **26**: 1412-1421.

Bhagyalakshmi, P. Hema. 2006. Studies on osmotic dehydration of bottle gourd (*lagenaria siceraria*). M. Tech. thesis, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.).

Bhuyan, M. and Prasad, T. 1990. Thin layer drying of siliguri variety of ginger. *Drying Technology*, **20** (10): 1989-2004.

Brandao, M. C. C., Maia, G.A., Lima, D. P., Parente, E. J. De. 2003. Physical and chemical, microbiological and sensorial analysis of cashew apples submitted to osmotic-solar dehydration. *Revista Ciencia Agronomica,* **34** (2): 139-145.

Brandao, M. C. C., Maia, G. A., Lima, D. P. 2003. Physicochemical, microbiological and sensorial analysis of fruits of mango submitted to osmotic-solar dehydration. *Journal of Food Science,* **25** (1): 38-41.

Camacho, A., Flink, J. M. 2006. Soluble micronutrients flow from grapefruit during osmotic dehydration. *Journal of Food Engineering*, **42**: 344-352.

Chandra, Suresh and Samsher, S. 2006. Dehydration and sensory quality evaluation of edible mushrooms: a critical review. *Journal of Food Science and Technology*, **43** (3): 221-227.

Chakraborty, Subir, Kumbhar, B. K., Sarkar, B. C. 2007. Process parameter optimization for instant pigeonpea dhal using response surface methodology. *Journal of Food Engineering*, **81**: 171-178.

Chenlo, F., Moreira, R., Pereira, G. and Ampudia, A. 2002. Viscosities of aqueous solutions of sucrose and sodium chloride of interest in osmotic dehydration processes. *Journal of Food Engineering*, **54**: 347–352.

Choudhary, P. L. 2007. Practical manual of food chemistry. I.G.K.V. publishing.

Cochran, W. G. and Cox, G. M. 1994. Experimental design. Some methods for the study of response surfaces. Chapter 8, pp. 335-375.

Collignan, A. and Raoult-Wack, A. L. 1994. Dewatering and salting of cod by immersion in sugar/salt solutions. *Lebensmittel-Wissenschauft und Technologi*e, **27**: 259–264.

Cruz, G. A. and Menegalli, H. 2004. Mass exchange during osmo-air drying of aubergine. *Journal of Food Engineering*, **49**: 137-140.

Debnath, S., Hemavathy, J., Bhat, K. K. and Rastogi, N. K. 2004. Rehydration characteristics of osmotic pretreated and dried onion. *Food and Bioproducts Processing.* **82** (C4): 304-310.

El Shiatry, M. A., Muller, J. and Muhlbauer, W. 1991. Drying fruits and vegetables with solar energy in Egypt. *Agricultural Mechanization in Asia, Africa and Latin America,* **22** (4): 61-64.

Erbay, Zafer, Icier, Filiz. 2009. Optimization of hot air drying of olive leaves using response surface methodology. *Journal of Food Engineering,* **91**: 533-541.

Eren, Ismail, Figen, Kaymak. 2007. Optimization of osmotic dehydration of potato using response surface methodology. *Journal of Food Engineering*, **79**: 344-352.

Ertekin, F. K. and Akaloz, T. 1996. Osmotic dehydration of peas-I. Influence of process variables on mass transfer. *Journal of Food Processing and Preservation*, **20**: 87–104.

Falade, S. and Aworth, B. 2005. Effect of osmotic dehydration pretreatment on quality of star apple and African mango. *Journal of Food Engineering,* **49** (4): 339-345.

Fan, L. P., Zhang, M., Xiao, G. N., Sun, J. C. and Tao, Q. 2005. The optimization of vacuum frying to dehydrate carrot chips. *International Journal of Food Science and Technology*, **40**: 911-919.

Genina, Soto P., Barrera Cortes, J., Gutierrez Lopez, G., Azuara Nieto, E. 2001. Temperature and concentration effects of osmotic media on OD profiles of sweet potato cubes. *Drying Technology*, **19** (3/4): 547-558.

Ghosh, P. K., Agrawal, Y. C., Jayas, D. S. and Kumbhar, B. K. 2006. Process development for osmo-hot air drying of carrot. *Journal of Food Science and Technology*, **43** (1): 65-68.

Giempero, S., Gianotti, A. and Dalla Rosa, M. 2001. Sucrose–salt combined effects on mass transfer kinetics and product acceptability. Study on apple osmotic treatments. *Journal of Food Engineering*, **49**: 163–173.

Giraldo, Bedoya D. P., Arango Velez, L. M. and Marquez Cardozo, C. J. 2004. Study on osmotic dehydration of jack fruit (*Artrocarpus integrifolia*). *Revista Facultad Nacional de Agronomia Medellin*, **57** (1): 2253-2268.

Gowda, S. J, Talukdar, K. C.and Ramaiah, H. 1992. Studies on drying characteristics of tomato seeds (Pusa Ruby) (Lycopersicon esculentum Mill.). *Progressive Horticulture,* **21** (3): 296-299.

Grabowski, S., Marcotte, M., Poirier, M. and Kudra, T. 2002. Drying characteristics of osmotically pretreated cranberries energy and quality aspects. *Drying Technology,* **20** (10): 1989-2004.

Hardeep Singh. 2001. Osmotic dehydration of carrot shreds for Gazraila preparation. *Journal of Food Science and Technology*. **38** (2): 152-154.

Hauser, M., El Bouamri, M. and Muhlbauer, W. 1993. Solar drying of apricots. *Arboriculture Fruitiere,* **46**: 33-40.

Jain, S. K., Verma, R. C., Mathur, A. N. and Murdia, L. K. 2004. Optimization of osmotic dehydration of papaya followed by air-drying. *Journal of Interacademicia,* **8** (2): 221-229.

Kar, Abhijeet and Gupta, D. K. 2001. Osmotic dehydration characteristics of button mushrooms. *Journal of Food Science and Technology*, **38**: 352–357.

Krokida, M. K., Oreopoulou, V., Maroulis, Z. B. and Marinos Kouris, D. 2001. Effect of osmotic dehydration pretreatment on quality of french fries. *Journal of Food Engineering,* **49** (4): 339-345.

Lazarides, H. N., Katsanidis, E. and Nickolaidis, A. 1995. Mass transfer kinetics during osmotic preconcentration aiming at minimal solid uptake. *Journal of Food Engineering*, **25**: 151–166.

Lee, W. C., Yusof, S., Hamid, B.S., Baharin, S. 2006. Optimization conditions for hot water extraction of banana juice using response surface methodology. *Journal of Food Engineering*, **75**: 473–479.

Lee, M. T., Edwards, D. G. and Asher, C. J. 1995. Ginger processing investigations: Improving the quality of processed ginger. *Journal of Food Science and Technology*, **50**: 1217–1219.

Lefort, J. F., Durance, T. D. and Updhyaya, M. K. 2003. Effects of tuber storage and cultivar on the quality of vacuum microwave-dried potato chips. *Journal of Food Science*, **68** (2): 690-696.

Lenart, A. 1989. Influence of osmotic substance on the kinetics of convection drying of apples and carrots. Annuals of Warsaw agricultural university-SGGW-AR. *Food Technology and Nutrition*, **18** (1): 27-35.

Lenart, A. and Flink, J. M. 1984 a. Osmotic dehydration of potato-I. Criteria for the end point of the osmosis process. *Journal of Food Science and Technology*, **19**: 45–63.

Lenart, A. 1995. Osmotic dehydration of fruits and vegetables. Handbook of industrial drying (2nd edition.). New York: Marcel Decker, Inc., pp. 691–713.

Lenart, A. and Flink, J. M. 1984 b. Osmotic dehydration of potato-II. Spatial distribution of the osmotic agent. *Journal of Food Technology*, **19**: 65–89.

Lerici, C. R., Pinnavaia, G., Dalla Rosa, M. and Bartolucci, L. 1985. Osmotic dehydration of fruit: Influence of osmotic agents on drying behavior and product quality. *Journal of Food Technology*, **18** (2): 667-685.

Lewicki, P. and Lenart, A. 1995. Osmotic dehydration of fruits and vegetables. Handbook of industrial drying (2nd ed.). New York: Marcel Decker, Inc., pp. 691–713.

Lis, T., Lis, H., Lis, M. and Lipnicki, L. 2000. Effect of cherry osmotic dehydration time on the kinetics of convection drying and qualitative properties of dried fruits. *Inzynieria-Rolnicza*, **4** (4): 61-67.

Maeda, M. and Loreto, R. L. 1998. Osmotic dehydration of bananas. *Semina Londrina*, **19** (1): 60-67.

Mantri, P. K. and Agrawal, D. S. 1986. Drying and dehydration of ginger. *Journal of Food Science and Technology*, **43** (1): 65-68.

Marcotte, M., Poirier, M. and Kudra, T. 2006. Drying characteristics of osmotically pretreated cranberries energy and quality aspects. *Drying Technology*, **20** (10): 1989-2004.

Mascheroni, R., Spiazzi, E., Wack, R. 2004. Mass transfer model for osmotic dehydration of fruits and vegetables-I. *Journal of Food Engineering*, **34**: 387–410.

Maura, M.A. and Menegalli, F.C. 2003. Evaluation of water and sucrose diffusion coefficients in potato tissue during osmotic concentration. *Journal of Food Engineering*, **57** (1): 367-374.

Michalik, M. and Bakowski T. 1994. Study on drying characteristics of onion. *Drying Technology*, **20** (10): 1989-2004.

Mishra, Ritesh (2007). Osmo-solar drying of bottle gourd (*lagenaria siceraria*). M. Tech. thesis, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.).

Moraga, G, Martinez Navarrete, N., Chiralt, A. 2006. Compositional changes of strawberry due to dehydration, cold storage and freezing-thawing processes. *Journal of Food Processing and Preservation*, **30** (4): 458-474.

Moura, C. P., Massona, M. L., Yamamotoa, C. I. 2005. Effect of osmotic dehydration in the apple (*pyrus malus*) varieties gala, gold and fuji. *Journal of Food Science and Technology*, **67**: 166-175.

Moreira, R. and Sereno, A. M. 2004. Control of solids uptake by convective drying prior to osmotic processing of foods. *Drying Technology*, **22** (4) : 221-226.

Moreira, R. and Sereno, A. M., 2001. Mass transfer coefficients during osmotic dehydration of apple in single and combined aqueous solutions of sugar and salt. *Journal of Food Engineering*, **47**: 43–49.

Moreira, R., Chenlo, F. and Pereira, G. 2003. Viscosities of ternary aqueous solutions with glucose and sodium chloride employed in osmotic dehydration operation. *Journal of Food Engineering*, **57**: 173–177.

Moreira R., Sereno A. M. 2003. Evaluation of mass transfer coefficients and volumetric shrinkage during dehydration of apple using sucrose solutions in static and non-static conditions. *Journal of Food Engineering*, **57**: 25-31.

Nieto, A. B., Salvatori, D. M., Castro, M. A., Alzamora, S. M. 2004. Structural changes in apple tissue during glucose and sucrose osmotic dehydration: Shrinkage, porosity, density and microscopic features. *Journal of Food Engineering*, **61**: 269-278.

Ndjouenkeu, R. 2003. Opportunity for improving the quality of tomato powder through the combination of osmotic dehydration and drying. Savanes africaines: des espaces en mutation, des acteurs face a de nouveaux defis. Actes du colloque, Garoua, Cameroon, 27-31.

Nehru, C., Kumar, V. J. F., Maheswari, C. U. and Gothandapani, L. 1995. Solar drying characteristics of oyster mushroom. *Mushroom Research*, **4** (1): 27-30.

Otoniel, Corzo, Nelson, Bracho, Alberto, Vasquez. 2008. Optimization of a thin layer drying process for coroba slices. *Journal of Food Engineering*, **85**: 372-380.

Otoniel, Corzo and Eddie R., Gomez. 2004. Optimization of osmotic dehydration of cantaloupe using desired function methodology. *Journal of Food Engineering*, **64**: 213-219.

Pande, V. K., Sonune, A.V. and Philip, S. K. 2000. Solar drying of coriander and methi leaves. *Journal of Food Science and Technology*, **37** (6): 592-595.

Park,K. J, Lima, A. M., Brod, F. P. R. and Nunes, A. S. 2000. Osmotic dehydration of green papaya dices. *Engenharia Agricola,* **20** (1): 45-54.

Pokharkar, B. 2001. Kinetic model for osmotic dehydration of green peas prior to air drying. *Journal of Food Science and Technology,* **38** (6): 557-560.

Ponting, J. D., Walters, G. G., Forrey, R. R., Jackson, R. and Stanley, W. L. 1966. Osmotic dehydration of fruits. *Food Technology*, **20**: 150–152.

Pruthi, J. S. 1980. Quality, package and storage of ginger. *Journal of Spices and Aromatic Crops*, **3**(1): 11-16.

Pruthi, J. S. 1993. Spices and condiments-chemistry, microbiology and technology. First edition. Academic Press Inc., New York, pp.1-15.

Puengphian, Chairat and Sirichote, Anchalee. 2007. [6]-gingerol content and bioactive properties of ginger (Zingiber officinale Roscoe) extracts from supercritical CO_2 extraction. *World Applied Sciences Journal*, **6** (4): 488-493.

Raghavan, G. S. V. and Sunjka, P. S. 2004. Assessment of pretreatment methods and osmotic dehydration for cranberries. *Canadian Biosystems Engineering,* **46**: 335-340.

Rahman, M. S., Sablani, S. S. and Al Ibrahim, M. A. 2001. Osmotic dehydration of potato: equilibrium kinetics. *Drying Technology*, **19** (6): 1163-1176.

Rahman, M.S. and Lamb, J. 1990. Osmotic dehydration of pineapple. *Journal of Food science and Technology*, **27** (3): 150-152.

Ramallo, P. and Rodolfo, M. 2005. Osmotic dehydration of pineapple slices: Influence of process variables on the quality. *Journal of Food Science and Technology*, **52**: 1217-12219.

Ramanathan, T. and Rao, P. 1974. Air drying of ginger. *Drying Technology*, **31**: 610-612.

Ranganna, S. 2000. Handbook of analysis and quality control for fruit and vegetable products. Second edition. Tata Mcgraw hill publishing.

Rao, Y. S., Madhusoodanan, KJ. and Potty, S.N. Large cardamom. 2008. Spices research and development in India - 50 years. Raveendran, P.N. (ed.), IISR, Calicut (In press).

Revaskar, N. and Kudra, P. 2005. Osmo-convective drying of onion slices. *Journal of Food Engineering*, **21**: 186-190.

Riva, B., Bellmawr, S., Poirier, C. 2005. Osmo-air drying of apricot cubes. *Journal of Food Science and Technology*, **26**: 1412-1421.

Rodriguez, H. 1971. Effects of calcium oxide treatment on colour of dried ginger. *Journal of Food Science and Technology*, **58** (6):1407-1410.

Raoult-Wack, A. L., Guilbert, S., Le Maguer, M., & Andrios, G. 1991. Simultaneous water and solute transport in shrinking media: application to dewatering and impregnation soaking process analysis (osmotic dehydration). *Drying Technology*, **9**: 589–612.

Sacchetti, G., Gianotti, A. and Dalla Rosa, M. 2001. Sucrose–salt combined effects on mass transfer kinetics and product acceptability. Study on apple osmotic treatment. *Journal of Food Engineering*, **49**: 163–173.

Saha, S., De, P. and Biswas, R. K. 1991. Solar dehydration of cabbage and carrot. *Environment and Ecology*, **9** (1): 244-248.

Sahari, M. A, Mahmoud Souti, Emam Jomeh, Z. 2006. Improving the dehydration of dried peach by osmotic method. *Journal of Food Technology*, **4** (3): 189-193.

Sanjinez Argandona, E. J., Cunha, R. L., Menegalli, F. C. and Hubinger, M. D. 2005. Evaluation of total carotenoids and ascorbic acid in osmotic pretreated guavas during convective drying. *Italian Journal of Food Science*, **17** (3): 305-314.

Sankari, C. R., Muthuswamy, S., Abdul, A. 1982. Ginger oil extraction from ginger. *Journal of Food Science and Technology*, **48**: 945-950.

Sankat, C. K. and Castaigne, F. 1992. Banana dehydration: osmotic, air and solar effects. *Drying 92*. Proceedings of the 8th International Drying Symposium (IDS '92), Montreal, Quebec, Canada.

Saputra, D. 2001. Osmotic dehydration of pineapple. *Drying Technology*, **19** (2): 415-425.

Selvaraj, J. A. 1988. Studies on sun drying of brinjal seed. *South Indian Horticulture*, **36** (5): 273-276.

Sereno, A. M., Mayor, L. and Moreira, R. 2004. Dehydration of pumpkin using salt as osmotic agent: Evaluation of water and salt coefficients of diffusion. *In*: *Drying 2004.* Proceedings of the 14th International Drying Symposium. Sao Paulo, Brazil, 22-25, pp. 2157-2164.

Sereno, A. M., Moreira, R. and Martinez, E. 2001. Mass transfer coefficients during osmotic dehydration of apple in single and combined aqueous solutions of sugar and salt. *Journal of Food Engineering*, **47**: 43–49.

Shi, J. and Le Maguer, M. 2002. Osmotic dehydration of foods: mass transfer and modeling aspects. *Food Reviews International*, **18**: 305–335.

Singh, Charanjiv, Sharma, H. K., Sarkar, B. C. 2008. Optimization of process conditions during osmotic dehydration of fresh pineapple. *Journal of Food Science and Technology*, **45** (4): 62-71.

Singh, S., Shivhare, U. S., Ahmed, J. and Raghavan, G. S. V. 2001. Osmotic concentration kinetics and quality of carrot preserve. *Food Research International*, **32**: 509–514.

Sousa, P. H. M de, Maia, G. A., Souza Filho, M., De., S., M., de., Figueiredo, R. W. De.; Nassu, R. T. and Borges, M. de. F. 2003. Evaluation of products obtained by the banana's osmotic dehydration followed of drying. *Boletim do Centro de Pesquisa e Processamento de Alimentos*, **21** (1): 109-120.

Souti, M, Sahari, M. A, Jomeh and Z. E. 2003. Improving the dehydration of dried peach by applying osmotic method. *Iranian Journal of Agricultural Sciences*, **34** (2): 283-291.

Souza Neto, M. A. De, Lima, J. R., Souza Filho, M. De., S. M. De., Souza, A. C. R. De., Maia, G. A. and Figueiredo, R. W. De. 2004. Development of a mango product by osmotic dehydration followed by oven drying. *Proceedings of the Interamerican Society for Tropical Horticulture,* **47**: 198-199.

Sultan, M., Kaymak, S., Agrawal, A. 2005. Quality evaluation of ginger. *Journal of Food Engineering*, **46**: 243–250.

Sunjka, P. S. and Raghavan, G. S. V. 2004. Assessment of pretreatment methods and osmotic dehydration for cranberries. *Canadian Biosystems Engineering*, **46**: 3.35-3.40.

Sutar, L. 1986. Studies on drying characteristics of ginger. *Drying Technology*, **19** (3): 583-597.

Tiroutchelvame, D. 2000. Studies on drying characteristics of ginger flakes. M. Tech. thesis, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.).

Themelin, A., Aymard, C., Lebert, A. and Guilbert, S. 1995. Effect of sucrose content on the moisture sorption isotherms of osmodehydrated apples at various temperatures. *Sciences des Aliments*, **15** (3): 237-249.

Torregiani, D. 1993. Osmotic dehydration in fruit and vegetable processing. *Food Research International*, **26**: 59–69.

Torre, M., Barron, M. E., Riaz, M. N. and Rooney, L. W. 2003. The properties of baked and fried tortilla chips fortified with mechanically-expelled soy flour. Poster presented at AACC meeting, Portland USA, 28th Sept - 2nd Oct.

Tyurin, Yu. G., Nabikhanov, B. M. and Abidov, T. Z. 1989. A solar drier for fruit. *Mekhanizatsiya I Elektrifikatsiya Selskogo Khozyaistva*, **5**: 37.

Uddin, M. Burhan, Paul, Ainsworth, Senol, Ibanoglu. 2004. Evaluation of mass exchange during osmotic dehydration of carrots using response surface methodology. *Journal of Food Engineering*, **65**: 473-477.

Waliszewski, K. N., Salgado Cervantes, M. A., Cortes Gonzalez, H. D., Romero Bello, M. I. and Sanchez Solis, A. J. 1994. Effect of pH, temperature and sucrose concentration on its hydrolysis rate during osmotic dehydration process. *Drying 94* Proceedings of the 9th International Drying Symposium, 985-991.

Yaldyz, O. and Ertekyn, C. 2001. Thin layer solar drying of some vegetables. *Drying Technology*, **19** (3): 583-597.

Yang, Zaibin, Xiaoyan, Zhao, Yang, Yufeng. 2009. Effect of superfine grinding on properties of ginger powder. *Journal of Food Engineering*, **91**: 217–222.

Yoonttee, Y., Baranowski, J. D., Anchalee, P.1995. Solar and hot air drying of ginger. *Journal of Food Science and Technology*, **50**: 932–933.

Zhang, M., Wang, C. Z. and Li, C. L. 1992. Study on osmotic dehydration and osmosed drying of eggplant. *Transactions of the Chinese Society of Agricultural Engineering*, **8** (4): 97-101.

http://books.google.co.in/books?hl=en&lr=&id=w5Echt6km94C&oi=fnd&pg=PA391&dq=ginger+powder&ots=LZG5tOwxdg&sig=3LxknR4fedYTR9R5GHMPYQOWnyw#PPR7,M1

http://www.indianspices.com/html/spices_board_resrchl_books.htm

http://www.indianspices.com

http://www.journal.au.edu/au_techno/2001/oct2001/article6.pdf

http://www.pbrc.edu/Division_of_Education/pdf/PNS_Ginger.pdf

http://www.pjbs.org/pjnonline/fin116.pdf

http://www.journal.au.edu/au_techno/2001/oct2001/article6.pdf

Appendices

Note: …… **Run No. :……..**

Observation sheet:

- Solution Temperature = …….. Osmosis time = …… Salt conc. = …….
- Mass Ratio = …….. Oven drying temp. = …… Initial wt. = …….

Osmotic dehydration:

	0 h	0.5 h	1 h	1.5 h	2 h	2.5 h	3 h	3.5 h	4 h	4.5 h	5 h	5.5 h	6 h	7 h	8 h
Wt.															
SG															
WR															
WL															
MC (db)															
MC (wb)															

Drying:

- Weight after osmosis = …….. Drying temp. = ……

	0	15	30	45	60	1.5h	2h	2.5h	3h	3.5h	4h	4.5h	5h	5.5h
Wt.														
Rh														
MC (db)														
MC (wb)														

- Final dried product weight = ……
- Final Moisture Content (wb) = …… Final Moisture Content (db) = ……

Initial M.C. (wb) = 82.86% **Initial M.C. (db) = 483.65%** **Sample Thickness = 3 mm**

Appendix-A

Appendix-B

Sensory Evaluation Sheet
(9-Point Hedonic Scale)

Test these samples and check how much you like or dislike each one. Use appropriate scale to show your attitude by assigning points that best describes your feeling about the sample. An honest expression of felling will help us.

Product: Osmo-Air Dried Ginger Slices

Sample No.	Colour	Appearance	Flavour	Taste	Texture (Mouth Feel)	Overall Acceptability	Remarks, if any
1.							
2.							
3.							
4.							
5.							

9-Point Hedonic Scale:

Like extremely	9	Dislike slightly	4
Like very much	8	Dislike moderate	3
Like moderate	7	Dislike very much	2
Like slightly	6	Dislike extremely	1
Neither like nor dislike	5		

Name & Signature

Appendix-C

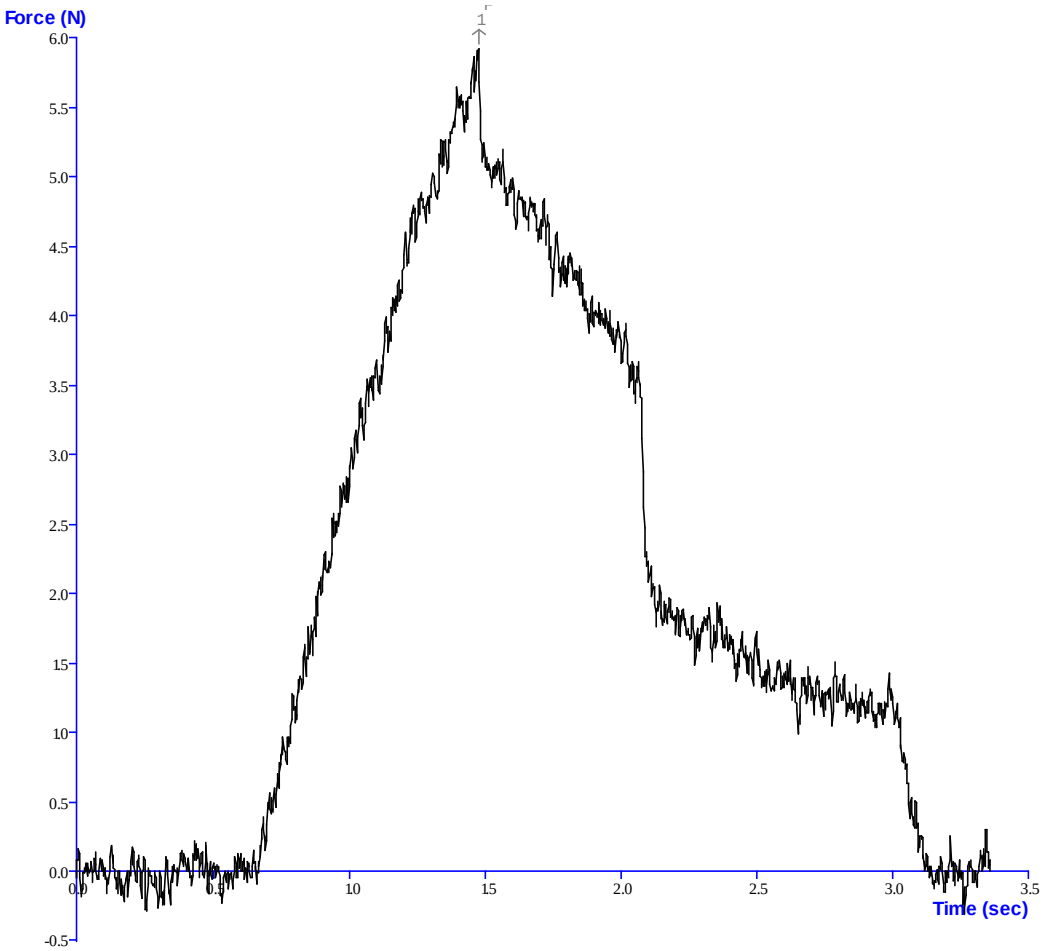

Fig. a: Hardness graph for osmo-air dried ginger slice dried 40^{o}C

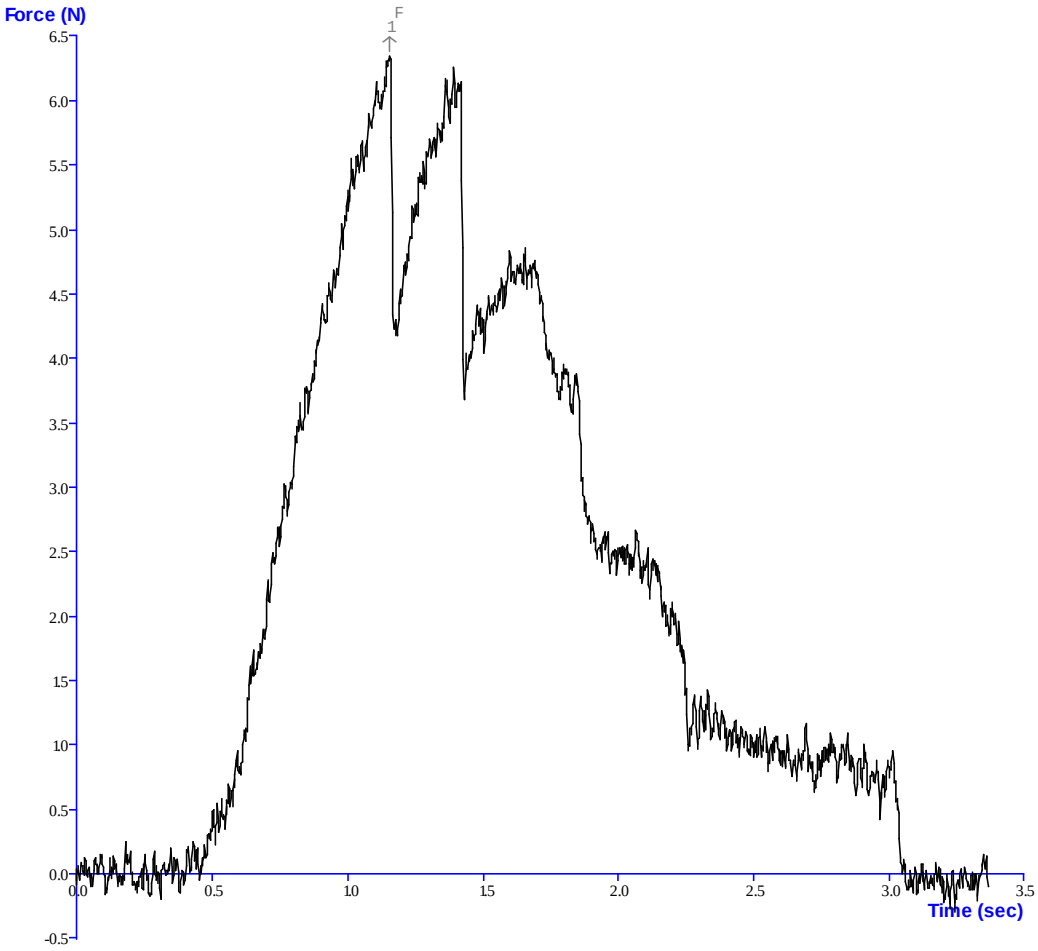

Fig. b: Hardness graph for osmo-air dried ginger slice dried 50^{o}C

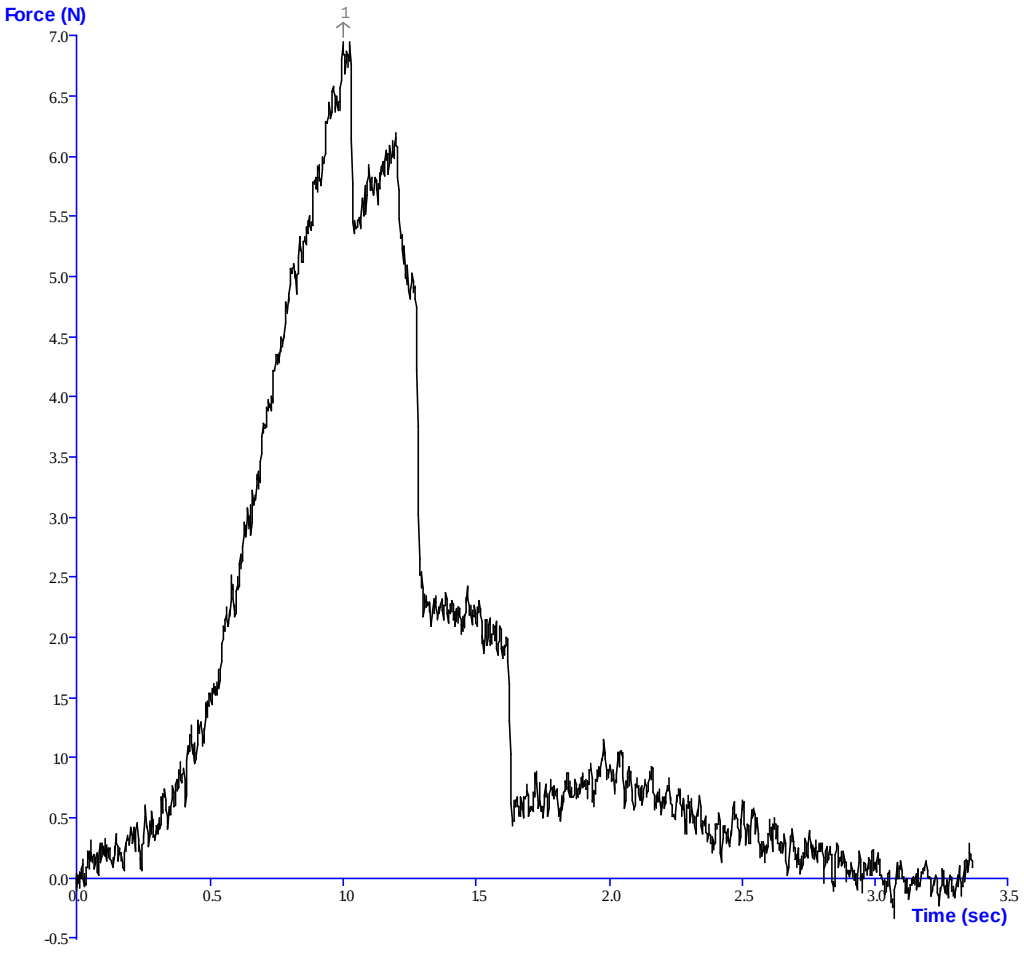

Fig. c: Hardness graph for osmo-air dried ginger slice dried 60^{o}C