

CONVECTIVE AND OSMO-CONVECTIVE DRYING CHARACTERISTICS OF MANGO AND CARROT

Submitted in partial fulfilment of the requirements for the award of
Bachelor of Technology degree in Chemical Engineering

By

ARNAB BHOWMIK (39690002)

PRASENJIT GUCHHAIT (39690012)



**DEPARTMENT OF CHEMICAL ENGINEERING
SCHOOL OF BIO & CHEMICAL ENGINEERING**

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with Grade "A" by NAAC

**JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119
NOVEMBER-2022**

CONVECTIVE AND OSMO-CONVECTIVE DRYING CHARACTERISTICS OF MANGO AND CARROT

Submitted in partial fulfilment of the requirements for the award of
Bachelor of Technology degree in Chemical Engineering

By

ARNAB BHOWMIK (39690002)
PRASENJIT GUCHHAIT (39690012)



DEPARTMENT OF CHEMICAL ENGINEERING
SCHOOL OF BIO & CHEMICAL ENGINEERING

SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)

Accredited with Grade "A" by NAAC

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600 119

NOVEMBER-2022



SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)

Accredited "A" Grade by NAAC | 12B Status by UGC | Approved by AICTE

www.sathyabama.ac.in

DEPARTMENT OF CHEMICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **Arnab Bhowmik (39690002)** and **Prasenjit Guchhait (39690012)** who carried out this Project entitled "**Convective and osmo-convective drying characteristics of mango and carrot**" under my supervision from July 2022 to October 2022.

Internal Guide

Dr. S. SATHISH M.E., Ph. D

(Associate Professor)

Dr. S. SATHISH, M.E., Ph. D

Head of the Department

HEAD OF THE DEPARTMENT
DEPARTMENT OF CHEMICAL ENGINEERING
SATHYABAMA
INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Jeppiaar Nagar, Rajiv Gandhi Salai,
Chennai - 600 119

Submitted for Viva-Voice Examination held on

Internal Examiner

External Examiner

DECLARATION

I, **Arnab Bhowmik (39690002)** hereby declare that this Project Report entitled “**Convective and osmo-convective drying characteristics of mango and carrot**” done by us under the guidance of **Dr. S. Sathish M.E., Ph. D** is submitted in partial fulfillment of the requirements for the award of Bachelor of Technology, degree in Chemical Engineering.

DATE:

PLACE: CHENNAI



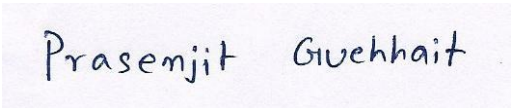
ARNAB BHOWMIK

DECLARATION

I, **Prasenjit Guchhait (39690012)** hereby declare that this Project Report entitled "**Convective and osmo-convective drying characteristics of mango and carrot**" done by us under the guidance of **Dr. S. Sathish M.E., Ph. D** is submitted in partial fulfillment of the requirements for the award of Bachelor of Technology, degree in Chemical Engineering.

DATE:

PLACE: CHENNAI

A rectangular box containing a handwritten signature in blue ink that reads "Prasenjit Guchhait".

PRASENJIT GUCHHAIT

ACKNOWLEDGEMENT

We are pleased to acknowledge my sincere thanks to The Board of Management of SATHYABAMA for their encouragement in doing this project and for completing it successfully. I am grateful them.

We convey my thanks to Dr. Sathish M.E., Ph.D., Head of the Department, Department of Chemical Engineering for providing us necessary support and details at the right time during the progressive reviews.

We would like to express our sincere and deep sense of gratitude to my Project Guide Dr. S. Sathish M.E., Ph. D for his valuable guidance, suggestions and constant encouragement paved way for the successful completion of my project work.

We wish to express our thanks to all Teaching and Non-teaching staff members of the Department of chemical engineering who were helpful in many ways for the completion of the project.

ARNAB BHOWMIK

PRASENJIT GUCHHAIT

ABSTRACT

Drying seasonal fruit and vegetables are essential for safe storage and preservation by reducing the moisture content to a certain level. In this study, green mangoes and carrots were treated with an osmotic solution and followed by dried in a micro oven-assisted convective dryer. The green mangoes sample was treated with 10 % (w/w) NaCl solution for 4 h, and carrot slices were osmotically dehydrated with 30 % honey (w/w) for 10 h. The moisture content was reduced after osmotic treatment were 5.2 and 5 % for green mangoes and carrots, respectively. Moreover, the behavior of convective and osmo-convective drying was investigated. Furthermore, the curve for moisture %, drying rate, and convective drying were plotted. The results show that the osmo-convective process reduced the time consumption for the drying than regular convective drying at the same temperature. It was reduced to 70 and 20 min for green mangoes and carrots, respectively. Altogether, osmotic dehydration followed by convective drying is a commercially acceptable process for the preservation of fruits and vegetables without altering the nutrition value.

Contents

Title page	i
Bonafide certificate	ii
Declaration	iii-iv
Acknowledgement	v
Abstract	vi
Contents	vii-ix
List of Figures	X
List of Tables	xi
List of Symbols	xii
Chapter 1 Introduction	1-11
1.1 Drying techniques	2-8
1.1.1 Natural drying	2
1.1.1.1 Solar drying	2
1.1.2 Artificial drying	3-5
1.1.2.1 Convective drying	3
1.1.2.2 Drying by radiation	3
1.1.2.3 Freeze drying	3-4
1.1.2.4 Ultrasound drying	4
1.1.2.5 Other techniques for drying	4-8

1.2	Osmotic dehydration	9-11
1.2.1	Principles of osmotic dehydration	9-10
1.2.2	Mechanism of mass transfer through osmotic dehydration	10-11
1.3	Osmo-convective drying	11
Chapter 2	Literature review	12-19
2.1	Osmotic process influencing parameters	12-17
2.1.1	Pre-treatment methods	12
2.1.2	Types of osmotic agent	12-13
2.1.3	Concentration of osmotic solution	13
2.1.4	Temperature of osmotic solution	13-14
2.1.5	Process duration	14
2.1.6	Agitation during osmotic dehydration	14
2.1.7	Sample to solution ratio	16-17
2.2	Reuse of osmotic solution	17
2.3	Application of osmotic dehydration process	17-18
2.4	Storage of osmo-dehydrated products	18
2.5	Economic benefits of osmotic dehydration	19
Chapter 3	Aim and scope	20
Chapter 4	Material and method	21-25
4.1	Materials	21

4.2	Sample preparation	20
4.3	Osmotic treatment	20
4.4	Convective drying	23
4.5	Quality evaluation	23-24
4.6	Drying Characteristics	24-25
4.6.1	Moisture content	24
4.6.2	Drying rate	24
4.6.3	Water content	25
Chapter 5	Result and discussions	25-31
5.1	Drying characteristics	25-30
5.1.1	Effect of moisture % of convective and osmo-convective drying	25-26
5.1.2	Drying rate curve for convective and osmo-convective drying	26-27
5.1.3	Drying curve for convective and osmo-convective drying	28-30
5.2	Nutritional value analysis	30-31
Chapter 6	Conclusion	32
	References	33-38

List of Figures

Figure No.	Caption	Page No.
1.1	Mechanism of osmotic dehydration	9
1.2	Osmotic process influencing parameters	12
4.1	Process flow diagram of convective and osmo-convective drying of mango and carrot	21
4.2	Experimental setup for osmo-convective drying of green mangoes and carrots	22
5.1	Moisture % (w.b) during osmo-convective drying and convective drying for green mango	25
5.2	Moisture % (w.b) during osmo-convective drying and convective drying for carrot	26
5.3	Osmo-convective and convective drying rate curve for green mango	27
5.4	Osmo-convective and convective drying rate curve for carrot	27
5.5	Osmo-convective and convective drying curve for green mango	28
5.6	Osmo-convective and convective drying curve for carrot	29

List of Tables

Table No	Caption	Page No.
1.1	Different drying techniques with their advantage and disadvantage	6
2.1	Osmo-convective drying of different fruits and vegetables	14
4.1	Test methods applied for quality evaluation	23
5.1	Nutritive value of fresh and osmo-convective dried mango	30
5.2	Nutritive value of fresh and osmo-convective dried carrot	31

Nomenclature

Symbols

W_1	mass of original sample
W_2	mass of dry sample
R	<i>Drying rate</i>

Abbreviations

WML	Initial weight of sample – Weight of sample after time (t)
DM	Dry material
d.b	Dry basis

CHAPTER-1

INTRODUCTION

In the typical human diet, fruits and vegetables play a significant role as sources of nutraceuticals. The term "nutraceuticals" refers to substances that are naturally present in foods or other ingestible forms and that have been shown to be advantageous to the human body in terms of either improving physiological performance beyond the effects of adequate nutrition or preventing or treating one or more diseases in a way that is relevant to both an improved stage of health and well-being and a decreased risk of disease. These ingredients may include advantageous antioxidants, natural colourants (such carotenoids), minerals, and vitamins, many of which may have additional benefits ^{1,2}. India offers a diverse spectrum of climatic and physio-geographical conditions, ensuring the availability of most fruits and vegetables. An estimated 486 million tonnes of vegetables and 392 million tonnes of fruits are produced worldwide each year. India is the second-largest producer of fruits and vegetables in the world, producing 90.534 million tonnes of every year (National Horticulture Board 2015–2016).

Although fruits and vegetables are produced during peak seasons, there are insufficient preservation and storage facilities at those times, thus the market becomes overstocked and gets rotten before it reaches the consumer. A lack of postharvest handling up to consumption causes between 30–40% of the overall yield in affluent countries to perish. However, postharvest losses in developing nations like India were close to 50% of the total production of fruits and vegetables, which has a negative impact on the consumers' access to fresh produce ³. Transforming it into a variety of commodities for sale, such as slices, powder, juice, or concentrate, would be one efficient way to lessen this enormous waste. The advantages of processed products include a longer shelf life, greater bacterial resistance, and less expensive handling, transportation, and storage. As a result, it's essential to produce a finished good that is both healthful and of acceptable quality for consumers ⁴. Food products are frequently preserved using a variety of techniques, including smoking, dehydration, and minimal processing. It dried to remove moisture, preserving and extending shelf life so that dried goods can be sold year-round and, in the places, where these are not produced. Moreover, drying

lowers the price of packaging, handling, and transportation in addition to reducing bulk and weight. However, food quality alterations in terms of physical, sensory, nutritional, and microbiological aspects could potentially result from drying ⁵.

1.1 DRYING TECHNIQUES

Drying is a mass transfer technique used to reduce the bulk of agricultural output by removing moisture from food products ⁶. Since drying requires the transfer of heat, modern drying focused on use of less energy, improve drying efficiency, and produce high-quality items at the lowest cost ⁷.

1.1.1 *Natural drying*

1.1.1.1 Solar drying

Since the beginnings of civilization, people have dried agricultural products using the sun, a free and endless source of energy that is as old as the universe itself. There are two types of solar drying: direct and indirect. This is a conventional technique for drying food products using the sun. Before packing, foodstuff gets dried off by being exposed to the sun for several days. In underdeveloped nations where fuel is expensive and limited, this is fairly typical. Due to its simplicity and low cost, sun drying is a widely used dehydration technique. Nonetheless, this drying method has some significant drawbacks, including poor product quality, insect attack, contamination with dust and filth, lengthy drying times, uncontrolled sunshine exposure⁸. Moreover, low heat transmission rates due to condensation of evaporated moisture. However, solar drying could be utilised to enhance the sun drying process. A few types of solar dryers are chamber type, chimney type, and wind-ventilated dryers. Again, in the indirect method of solar drying, heat is produced by the solar system and directed into the foods to be dried by air movement, heating the finished product with the top vented facility in the drying chamber to remove the evaporated moisture ⁹.

1.1.2 *Artificial drying*

1.1.2.1 *Convective drying*

The most popular technique for removing moisture from food items is convective hot air drying of agricultural produce. Using modern heating equipment,

the convective method of drying is utilised to remove water. In order to properly remove moisture hot air is used to transfer heat to the food products. Food drying equipment could include a hot air tunnel dryer ¹⁰, tray dryer ¹¹, cabinet dryer ¹².

1.1.2.2 Drying by radiation

It has been reported that long drying times and high hot air-drying temperatures cause the loss of foods' heat-sensitive components. An alternate technique to hot air drying that could be utilised to solve the issues is radiation drying. Microwave radiation, which employs electromagnetic energy, is used to dry food stuffs¹³. In order to spread microwave heat through space, electric and magnetic fields are used. Microwave drying of food products has been discovered to generate better-quality dried goods and to eliminate moisture from food products more quickly and at a lower temperature¹⁴.

1.1.2.3 Freeze drying

According to IFT, "freeze-drying is the method through which the solvent (mainly water) or suspension medium is crystallised at low temperature and eliminated by sublimation. Water sublimates i.e directly changes from a solid state to a gaseous state, without melting. Hence, freeze drying is a procedure involves drying the food product through freezing and direct subtraction of solvents accompanying with the food by sublimation¹⁵. Since technique requires dehydration at low temperatures through freezing at lower pressure followed by sublimation of the ice, freeze drying is also known as lyophilisation or cryodesiccation. This distinguishes freeze drying from the majority of traditional procedures, which involve the application of heat to remove water¹³. Moreover, in the first phase of freeze drying has been found to produce superior quality dried goods since there was no liquid water present throughout the freezing process, the drying temperature was low, processes involving microorganisms ceased, and the food products could be successfully rehydrated. However, investigators observed that variation in the rehydration property of freeze-dried products. Pectin cell breakdown, changes in water crystal size, and porosity as a result of salt concentration imposed by water absorption. As compared to other drying techniques, freeze-drying produces dried foods of the finest quality due to the preservation of flavour and structural integrity. Even though it is expensive, freeze drying is only utilised for high-value products

including seasonal fruits and vegetables, coffee, and consumables for the military, astronauts/cosmonauts, and hikers¹⁶. Products that have been freeze-dried show quick rehydration, good organoleptic properties, low chemical change, less volume loss, greater retention of vitamins, antioxidants, and colourants, and minimum chemical change. Despite the benefits, there are a number of drawbacks to freeze drying, including expensive equipment costs and considerable energy usage during the freezing, drying, and condensing processes.

1.1.2.4 Ultrasound drying

In comparison to traditional hot air drying, food could be dried using ultrasound to improve the attributes and quality of the items. Ultrasonic energy can be used on its own or in combination with other energies, such as hot air. Moreover, by reducing temperature or treatment time, ultrasound enhances the quality of the final product. The use of ultrasound to dry food speeds up the drying process and uses less energy. Researchers noticed that the resulting product quality was superior to that of control operations without ultrasonic enhancement due to the slight "temperature impact". It was also noted that the main barrier for industrial application of ultrasonic technology was defined as the lack of an appropriate method for generating power ultrasound in air¹⁷. Bell pepper was dried an integrated ultrasound freeze drying system that could be used to dry various food items. Many researchers reported that the impart heating effect of the food stuffs when ultrasound was applied continuously, even at low ambient pressure. Additionally, the using of ultrasound minimized the drying time by 11.5%¹⁸.

1.1.2.5 Other techniques for drying

Other artificial drying methods are dielectric drying, microwave drying, radio frequency drying, electro-hydrodynamic drying, fluidized-bed drying, low-pressure superheated steam drying etc. Microwave and radio frequency electromagnetic energy directed and allowed to interact with food interiors, it rapidly raises the centre temperature to promote drying of the food products¹⁹. Microwave drying includes the drying of foodstuffs using a microwave. Heat transfer occurs during the dehydration of foods as microwave energy penetrated and heats it without forming thermal gradients. Food products can absorb microwave radiation, which causes it to be

transformed into heat. However, microwave heating has a number of drawbacks, including uneven material drying, shallow heat penetration, and the "puffing" phenomena²⁰.

In recent years, radio frequency drying, which involves heating food with radio frequency radiation to provide quick and efficient thermal treatment for drying purposes, has gained more popularity. On the basis of coupled mechanisms of dipole rotation and conduction effects, radio frequency energy has been noticed to volumetrically release heat within food, resulting the enhancement of the drying process of food products²¹. However, it has been discovered that radio frequency thermal treatments can minimise the loss of thermal quality in drying items. Moreover, non-uniform heating and runaway heating are the main drawbacks of radio frequency heating, which can cause overheating in the corners, edges, and core sections, especially in products with intermediate and high moisture contents. Relative to conduction, radiation, or other methods of heat transmission, electro-hydrodynamic drying is a new drying technique that is not as well-known. It is a non-thermal drying method used to dry heat-sensitive materials. In this technique, drying is performed by supplying a strong electric field to a single or a group of electrodes, and to speed up the drying process, a plate electrode is also employed. Moreover, quick evaporative cooling and dipole orientation in the electric field, drying is accomplished at lower drying temperatures and entropies²².

Food ingredients in granular form are dried using fluidized beds. It has a number of benefits, including effective, affordable, and durable drying equipment. This kind of drying enables efficient mass and heat transmission between the drying medium and the food ingredients. Along with a faster drying rate, it also produces high-quality dried food products. Food items such as waxy rice ²³, sliced potatoes ²⁴,maize ²⁵ had dried using this technique. Several food products have been dried using superheated steam. This process is environmentally friendly, reduces the risk of fire and explosion, uses less energy, has a high drying rate, and yields dried goods of excellent quality²⁶. However, there are significant drawbacks when used to dry foods that are heat-sensitive. Furthermore, dry heat- and oxygen-sensitive items have been exposed to superheated steam at low pressure, which has effectively preserved the physical and chemical characteristics of such food products²⁷.

Table 1.1: Different drying techniques with their advantage and disadvantage

Drying techniques		Advantage	Disadvantage
Natural drying	Solar drying	• Sun is as old as the universe itself and is a free and an inexhaustible source of energy • Sun drying is a commonly used method of drying due to its simplicity and cheapness	• Poor products quality as a result of insect attack • Contamination with dust and dirt • Long drying time and unregulated exposure sunlight • Poor heat transmission rate because of condensation of evaporated moisture
	Drying by radiation	• Heat sensitive components of foods are lost as a result of long drying time and high temperature. • It's an alternative method that could be used to overcome the problems encountered in hot air drying	• Scorching has been a problem with microwave heating due to reduced moisture towards the end of the drying process
Artificial drying	Freeze drying	• Superior quality dried product as a result of absence of liquid water during freezing • Low temperature of drying with cessation of reactions involving microorganisms	• Freeze drying is costly and thereby used for drying high-value products such as seasonal fruits and vegetables • Example: coffee and foods used for military, astronauts/cosmonauts and/or hikers.

Ultrasound drying	• Application of ultrasound to dry food shortens the drying time • Reduces total energy consumption	• lack of an effective technology for generating power ultrasound in air was distinguished as the primary constraint for industrial application of ultrasound technology
Osmotic drying	• It involves removal of water from plant tissues by immersion in a hypertonic solution which results into a concentration differential between the moisture of food to be dried and the solution	• the osmotic drying process is economical • It depends on: temperature of osmotic solution, concentration of the osmotic solution, osmotic agent used, process duration and geometry of food material
Convective drying	• Convective method of drying is used to remove water from agricultural produce through heat transfer in modern heating equipment. • This involves the use of hot air to transfer heat to the food products and remove moisture effectively from the food products	• Heat sensitive components of foods are lost as a result of long drying time and high temperature of hot air drying

1.2 OSMOTIC DEHYDRATION

Osmotic dehydration is a technique widely employed as a pre-treatment to lessen the negative effects of convective drying in the third generation of drying²⁸. Moreover, it is a quick and easy method that preserves the nutritional value, colour, flavour, and texture of fruits and vegetables during processing. It has no adverse effects on the body as there are no chemicals used in its preservation²⁹.

1.2.1 Principles of osmotic dehydration

The physico-chemical changes that occur in the product throughout the dehydration process have been thoroughly explored in relation to emerging novel techniques. Drying can enhance the quality of materials that might create value-added chemicals during the drying process, such as spices, medicinal plants, herbs, nuts, fruits, and vegetables in addition to protecting the product³⁰. In order to create fruit and vegetable matrices to which functional components can be successfully added, osmotic dehydration soaking seems to be a promising approach. This could lead to the development of innovative functional goods and new economic prospects. Due to its minimal treatment, the production of food with an intermediate moisture content using osmotic dehydration has attracted a lot of consumer attention recently³¹.

Foods like fruits and vegetables can be osmotically dehydrated by submerging them in concentrated soluble solid solutions with increased osmotic pressure and decreased water activity. Since food and the osmotic medium have different chemical potentials for water, dehydration results from this. Moreover, the process of osmotic dehydration results in simultaneous tissue shrinkage and mass transfer. However, osmotic dehydration is a combination of water and solute diffusion processes since it is difficult to develop a fully semi-permeable membrane in food systems and occasionally solid diffusion occurs into the food³².

Since most food materials contain a considerable amount of water, the main benefit is to limit the water activity of the food materials, hence reducing the growth of microorganisms. Therefore, these are economical to store and transport. Although phase shift is not required, osmotic dehydration is found to be an energy-efficient approach of partial dehydration. Additional options include fortifying food with substances that can change its structural, functional, and nutritional aspects, as well as food composition that lowers water activity. Moreover, it works well at room temperature, minimising the effects of oxidative changes and heat damage to colour, texture, and flavour as well as the loss of volatile ingredients³³.

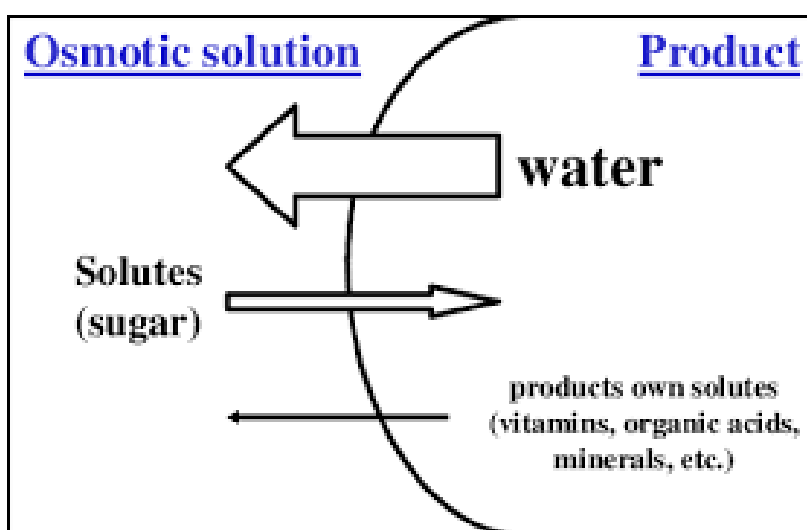


Fig: 1.1: Mechanism of osmotic dehydration

1.2.2 Mechanism of mass transfer through osmotic dehydration

A counter-current mass transfer takes place when the product interacts with a low water activity solution during osmotic dehydration. Water is transferred from the product to the solution, and in the opposite way, soluble solids from the osmotic solution are incorporated into the food substance. The food industry has adopted a pre-treatment method that involves the partial loss of water from plant tissues caused by immersion in a hypertonic (osmotic) solution, as shown in Figure 1.

Water from the tissue flows into the hypertonic solution when the osmotic pressure is raised. Solutes from osmotic solutions reach the tissue through counter-diffusion. Additionally, a lack of complete selectivity in the osmotic membrane it also allows other solutes in the cells to leach into the osmotic solution. Furthermore, depending on factors like temperature, concentration, size, geometry, and the ratio

of the solution to the material, the substance containing plant tissues will diffuse water at a varying rate.

Three different forms of counter mass transfer are listed by the osmotic dehydration process,

- Water initially diffuses more quickly from the product into the solution, then more slowly.
- Solutes moving from the solution to the finished product. It introduces a preservative, another nutrient-dense substance, and also enhances the product's flavour and texture.
- Leaching out of the own solute of product (such as sugar, organic acids, minerals, vitamins, and so on), which is less significant than the first two types of transfer but essential to the final product constitution

1.3 OSMO-CONVECTIVE DRYING

Convective hot air drying at high temperatures causes the product to undergo physical and biological changes. These modifications typically have negative effects on areas of product quality such vitamin degradation and browning reaction. Therefore, choosing the right drying techniques and optimising the drying conditions are crucial for enhancing product quality³⁴. In the food processing industry, osmotic dehydration is an additional treatment and food preservation method. It minimizes the impact that heat had upon flavour, colour, and enzymes browning. As it can be done at low or ambient temperatures, it requires less energy than air or vacuum drying. However, osmotic dehydration might not produce a product with a low enough moisture content to make it shelf-stable, thus additional processing, like air drying, vacuum drying, or freeze-drying, is required. As a result, a different drying technique that combines osmosis with partial fruit dehydration has drawn interest in recent years. It is a method for producing foods with intermediate levels of moisture and foods that are shelf-stable as well as for use as a pre-treatment before drying to minimise energy consumption and heat damage³⁵.

CHAPTER-2

LITERATURE REVIEW

2.1 OSMOTIC PROCESS INFLUENCING PARAMETERS

2.1.1 Pre-treatment

Many researchers have used pre-treatments like blanching, sulfiting, alkaline dipping, utilisation of high hydrostatic pressure, and freezing before osmotic dehydration to decrease the detrimental alterations to biological components resulting from conventional drying methods. Blanching and osmotic pre-treatments of carrot slices prior to drying resulted in improved nutritional value and sensory acceptability³⁶. However, the blanching pre-treatment of vegetable pieces at a temperature of 100 °C for 10-30 s increased the efficient water and sucrose diffusion coefficients. Consequently, pre-treating produce with sulphur dioxide or blanching³⁷ can prevent fruit and vegetable discolouration³⁷. Slices of papaya and mango were soaked in 0.4% ascorbic acid solution and 0.4% ascorbic acid + 0.1% KMS solution for 30 minutes prior to osmotic dehydration, producing a highly satisfactory product. Moreover, food materials that were immersed in acid or alkaline solutions prior to drying retained their colour. Fruits and vegetables were protected from enzyme browning by dipping them in a 1.0% citric acid solution before to osmotic dehydration³⁸.

2.1.2 Type of osmotic agent

Sucrose and sodium chloride are the most commonly used osmotic agents in fruits and vegetables, respectively. Other osmotic agents include glucose, fructose, lactose, dextrose, maltose, polysaccharides, maltodextrin, corn starch syrup, and others. The osmotic agent used must be safe and tasty. Moreover, high fructose corn syrup has a higher diffusivity during osmotic dehydration of apple than sucrose. Because of the high velocity of molecule penetration, lower molecular mass saccharides (glucose, fructose, sorbital, etc.) favour sugar uptake, so solid enrichment rather than dehydration is the main effect of the process. As the dextrose equivalent value increased, the water activity lowering capacity increased. There were logarithmic relationships discovered between molecular weight and dextrose

equivalent³⁹. However, as the solid contents increased, the diffusion coefficient decreased⁴⁰. This was linked to the formation of a barrier layer, which was aided by high molecular weight solutes, preventing the loss of natural fruit solutes⁴¹.

2.1.3 Concentration of osmotic solution

The type of sugar and its concentration as an osmotic substance have a significant impact on the kinetics of water removal, solid gain, and equilibrium water content. Weight loss and dehydration aspects of the process are favoured by increasing the molar mass of the solute, and both equilibrium and drying rate increase with increasing osmotic syrup concentration⁴².

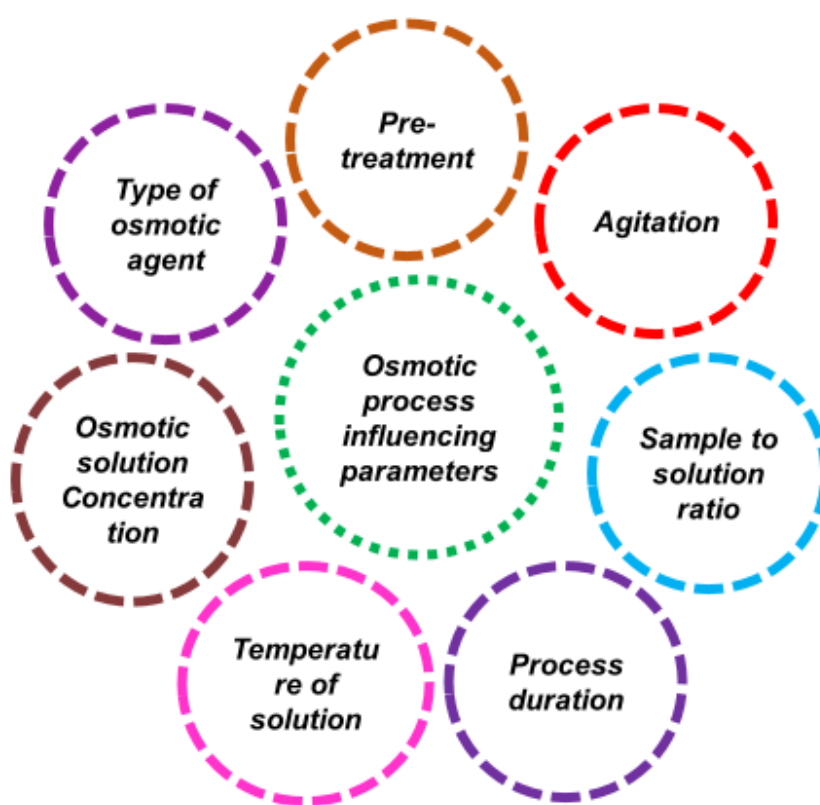


Fig: 1.2: Osmotic process influencing parameters

2.1.4 Temperature of osmotic solution

Temperature has a significant impact on the rate of osmosis. This is the most important factor influencing kinetics. Many researchers have conducted extensive research on the temperature of the osmotic process⁴³. Water loss increases as temperature rises, whereas solid gain is less affected by temperature. The rate of osmosis increases the mass exchange and diffusion coefficient, but above 50 °C, enzymatic browning and flavour deterioration occur. Ascorbic acid and chlorophyll

retention are also significantly affected. High temperatures above 60°C alter tissue properties, favouring the impregnation phenomenon and thus solid gain. Moreover, water loss and solid gain increase in temperature up to 50 °C depending on the fruit and variety, then fall sharply to become nearly constant at 60 °C, indicating a negligible increase in the rate of sucrose diffusion above 60 °C⁴⁴.

2.1.5 Process duration

Increased immersion time results in greater moisture loss during osmotic dehydration. Previous research found that the solid gain and weight loss of the product during osmosis reach an equilibrium state with respect to time⁴⁵. Research into the impact of duration on the osmotic process revealed that mass exchange occurred at a faster rate during the first 2 hours, followed by a decrease in drying rate during the remaining process time. At a concentration of 45% to 60% and a temperature range of 20 to 50 °C, the apple slices lost about 25% of their water within the first hour and 40% after the third hour of osmotic treatment⁴⁶. However, the initial period of time is critical, because mass transfer phenomena seem to be rapid and have a significant impact on the osmotic process further progression³¹.

2.1.6 Agitation during osmotic dehydration process

Since the lowering in resistance caused by the localised dilution process, the osmotic mass transfer rate increases with agitation during the osmotic process. The use of highly concentrated sugar solutions causes issues such as floatation of food portions, which hinders contact between the osmotic solution and food materials, reducing mass transfer rates. Agitation has been shown to reduce the rate of solid gain over a longer process period⁴⁷. It could be caused by increased water loss, which changes the solute concentration gradient within the food material. As solute diffusion into the cell is slow, the majority of it accumulates as a thin subsurface layer. The mass transfer rate of agitated and non-agitated samples was investigated. Weight loss was greater in agitated samples than in non-agitated samples. Stirring causes turbulence, which increases the rate of diffusion during the process. Water loss was greater in the turbulent flow region than in the laminar flow region. As a result, agitation is a useful complementary process for increasing the

mass transfer rate by reducing the contact time between the food and the osmotic solution⁴⁸.

Table 2.1: Osmo-convective drying of different fruits and vegetables

Sl no.	Sample	Osmotic treatment	Convective drying	Reference
1.	Apple	- Osmotic agent: 40 % glucose solution - Room temperature - The material to solution ratio was 1:20 (w/w) - Time: 150 min	- Conventional cabinet dryer - Temperature: 105 °C - Time: 120 min	12
2.	Cauliflower Mushroom Greenpea	- Osmotic agent: Sugar-salt, salt, and sugar-salt plus $MgHCO_3$ - Time: 5 h - Osmotic agent: Sugar syrups	- Tray dryer maintained - Temperature: 60 °C	49
3.	Sapota (Chikko)	- Temperature: 50 °C - Time: 1 h - The ratio of syrup to sapota slice was 5:1 - Slices thickness: 0.3 cm	- Convective tray dryer - Temperature: 50-80 °C - Time: 5 h	50
4.	Fresh sweet oranges	- Osmotic agent: Sugar, jaggery, honey, stevia - Product/solution ratio was 1:5 - Temperature: 40 °C - Osmotic agent: sucralose solution	- Cabinet dryer - Temperature: 60 °C	51
5.	Yacon slices (Smallanthus sonchifolius) Camila	- Room temperature - The material to solution ratio was 1:20 (w/w) - Time: 2 h	- Tray dryer - Temperature: 60-80 °C - Time: 3 h	52
6.	Jackfruit (Artocarpus heterophyllus)	Osmotic agent: Salt solution (15% concentration)	- Tray dryer - Temperature: 50 - 70 °C	11

			Constant air flow velocity: 1.5 m/s	
7.	Carrot	- Osmotic agent: 60% sugar and 3% salt - Slices thickness: 10 mm - Time: 3 h - Temperature: 60 °C	- Tray dryer - Temperature: 60-70 °C - Time: 30 min	53
8.	Blueberries	Osmotic agent: sucrose	- Forced air cabinet dryer - Temperature: 50 ± 1 °C - Air velocity: 0.64 ± 0.02 m/s - Time: 30 min	54
9.	Beetroot	- Slices size: 1cm ×1cm×1cm - Time: 180 min - Temperature: 55 °C - fruit to solution ratio 1:4 (w/w)	- Temperature: 65 °C - Air velocity: 1.6 m/s	55

2.1.7 Sample to solution ratio

Another important parameter that influences osmosis is the solution-to-sample ratio. Up to a certain point, a change in ratio affects mass transfer during osmosis. The solution to sample ratio should be chosen carefully so that the driving force for moisture removal remains until the end of the process. When osmotic solutions become dilute, the driving force for water release decreases. As dehydration progresses, the osmotic solution becomes increasingly dilute, acting as a driving force for further water drop release⁴⁸. The majority of researchers used sample-to-solution ratios ranging from 1:1 to 1:5 to study mass transfer kinetics by monitoring in solution concentration and other factors. In osmotic dehydration, increasing the osmotic solution to sample mass ratio resulted in an increase in both solid gain and water loss. Most workers used a large solution to product ratio (at least 30:1) to avoid significant dilution of the medium and subsequent decrease of the (osmotic) driving force during the process, whereas some investigators used a much lower solution to product ratio (4:1 or 3:1) to monitor mass transfer by following changes in the concentration of the sugar solution. However, an optimum ratio is

required because large ratios present practical difficulties in handling the syrup fruit mixture for processing. For practical purposes, a ratio of 1:2 or 1:3 is ideal⁵⁶.

2.2 REUSE OF OSMOTIC SOLUTION

To make osmotic dehydration more economically appealing, the osmotic solution must be reconcentrated in some way, either by evaporation or by adding fresh osmotic reagent. It can be an efficient complementary processing step to thermal dehydration in the overall chain of integrated food preparation. The problems associated with used osmotic solutions are related to changes in properties (pH, viscosity, water activity of solution, sensory properties (primarily flavour and colour), and a raise in organic matters, which offers a substrate for microbial growth⁵⁷. The type of processed material, type of reconcentration method, pasteurisation parameters, process organisation, and individual adaptation to the particular process influence the spent solution management. The solution that was left over after osmotic treatment of fruits was suggested to be used in other food preparations such as jams, syrup for fruit canning, mixing with fruit juices, fruity soft drinks, pharmaceutical and food industries as natural additives, and feedstuffs production⁵⁸.

2.3 APPLICATION OF OSMOTIC DEHYDRATION PROCESS

Osmotic dehydration is primarily used to improve the nutritional, organoleptic, and functional qualities of a product. Since the process is carried out at room temperature, heat damage to colour and flavour is reduced, and the sugar surrounding fruit and vegetable pieces is concentrated, thereby preventing discoloration⁴⁸. Moreover, high-quality fruits and vegetables with functional qualities suitable for various food systems are achieved through selective enrichment in soluble solids and lowered acidity with little or no sulphur di oxide use. These advantages can be obtained while using less energy than a standard drying procedure. Furthermore, osmotic dehydration is a gentle processing technique with higher organoleptic affinity for natural and dehydrated products⁵⁶.

2.4 STORAGE OF OSMO-DEHYDRATED PRODUCTS

By addressing the issues of fruit glut seasons, most vegetables and fruits could be made available year around. To prevent moisture absorption from the atmosphere and other contaminations, osmo- dried foods are packaged in high-quality airtight containers and food grade cans. Packaging of osmo-dehydrated products should be done with laminated polypropylene pouches and aluminium foil. Furthermore, due to the reduced weight and volume of osmo-dehydrated food, significant cost savings in packaging and distribution may be possible, resulting in easier handling and transportation to the market. Osmo-dehydrated food can be stored at room temperature for 6 months to a year. Chemical reactions and the growth of toxin-producing microorganisms cease at lower water activity levels. The main concern for improving osmo-dehydrated food products is their microbial load, which may affect the shelf life of packaged products, particularly cut fruits. As a result, without any additional processing steps, the approach for reducing microbial load could reduce postharvest losses while maintaining costs, thereby adding value to food products. A suitable combination of water activity and pH was discovered to be very effective in controlling microbes in food. It has been discovered, for example, that pre-treatment with acid solutions inactivated *Escherichia coli* in dehydrated apples. The use of citric acid in various kinds of cut fruit and vegetables has been extensively accepted as a successful method of lowering the surface pH. The combination of low pH and water activity reduces microbial loads significantly. Water activity is an essential factor that affects microbial ecology and is critical for osmo-dehydrated product shelf life. It is identified as the accessible moisture content of a packaged food.

2.5 ECONOMICAL BENEFITS OF OSMOTIC DEHYDRATION

Over the last three decades, much research has been conducted on osmotic dehydration, and it has been discovered that it is one of the best methods for preservation because it does not destroy many nutritional parameters such as colour, flavour, and texture. Considering the significance of the field and its future potential, the European Commission has funded a project called "Improving food quality by applying osmotic treatments in conventional and new processes (FAIR-CT96-1118)" led by Professor W.E.L. Spiess of the Federal Research Centre for

Nutrition in Karlsruhe, Germany, and involving 13 other European countries⁵⁹. The method is indeed very simple, cost effective (energy requirements are 2-3 times lower than in conventional drying), and useful for producing safe, stable, nutritious, tasty, economical, and concentrated fruit products. It was discovered that combining the osmotic process with air or vacuum drying was less expensive than freeze-drying. The osmotic dehydration will be an important step in many processing operations in the future because it reflects a potential energy savings and an enhancement in overall food product quality⁶⁰.

CHAPTER-3

AIM AND SCOPE

Based on literature review taking account all the advantages of osmo-convective drying this research was conducted. In this experiment green mangoes and carrots were selected. As, mango is a well-known tropical fruit that is widely grown. The fruit is high in antioxidants and should be included in one's daily diet because of its health benefits, which include a lower risk of cardiovascular disease, anti-cancer, and anti-viral properties. It also contains a large quantity of β -carotene, a carotenoid, that is responsible for the typical yellow colour of the mangoes. Furthermore, as a provitamin A and antioxidant, β -carotene is extremely beneficial for human consumption.

On the other hand, Carrot is one of the most important root vegetable crops and is extremely nutritious, containing significant amounts of vitamins B1, B2, B6, and B12. It also contains a variety of essential minerals. Carrots have the largest β -carotene content of any human nutrition, with approximately 5-8 mg of β -carotene per 100 g. Carrot pigment β -carotene is a precursor to vitamin A. Carrots also have a high fibre content, which helps to maintain a balanced diet.

This research involves a combination of convective and osmo-convective drying of mangoes and carrots. This study includes osmotic treatment with salt solution and honey solution followed by drying.

The specific objectives of this research include,

- ❖ To study the drying characteristics of mango and carrot without treating osmotic solution.
- ❖ To study the osmotic behavior of mango and carrot.
- ❖ To study the drying characteristics of mango and carrot treated with osmotic solution.

CHAPTER-4

MATERIAL AND METHOD

4.1 MATERIALS

Fresh green mangoes (*Mangifera indica*) and carrots (*Daucus carota*) were procured from the local vegetable market at Madhavaram, Chennai, India (13.09° N, 80.13°E). The reagents used in the experiments were NaCl (purity: 99%) and Honey (purity: 100%). These were supplied by Merck India Ltd., Mumbai and local supermarket at Chennai, India. All experimental solutions were prepared with purified drinking water, which was obtained from the Livpure Smart Water Purifier unit.

4.2 SAMPLE PREPARATION

The mangoes and carrots were washed thoroughly with tap water to remove all the dirt and debris. These were peeled off and cut in small pieces with a sharp knife. The average size of the mangoes and carrots were 30*10*10 mm and 5mm slices respectively. These samples were weighed and used for further convective drying and osmo-convective drying. A stock solution of osmotic agent was prepared by dissolving accurately weighed amounts of NaCl and honey in purified drinking water. The desirable experimental concentrations of solutions were prepared by diluting the stock solution with purified water according to necessity.

4.3 OSMOTIC TREATMENT

Previously weighed mango pieces were subjected to osmotic treatment in 10 % NaCl solution, at room temperature of 30±5 °C. Moreover, the material to solution ratio was 1:10 (w/w) and samples were kept submerged for 4 h. Similarly, the slices of carrots were immersed into 30% of honey solution for 10 h with a ratio of 1:10 (w/w) sample to osmotic solution. The solution containing samples was stirred manually at a regular interval to make it uniform.

Furthermore, the solutions were drained after osmotic treatment. The samples were blotted with tissue paper to remove the excess of osmotic solution from their surface and weighed.

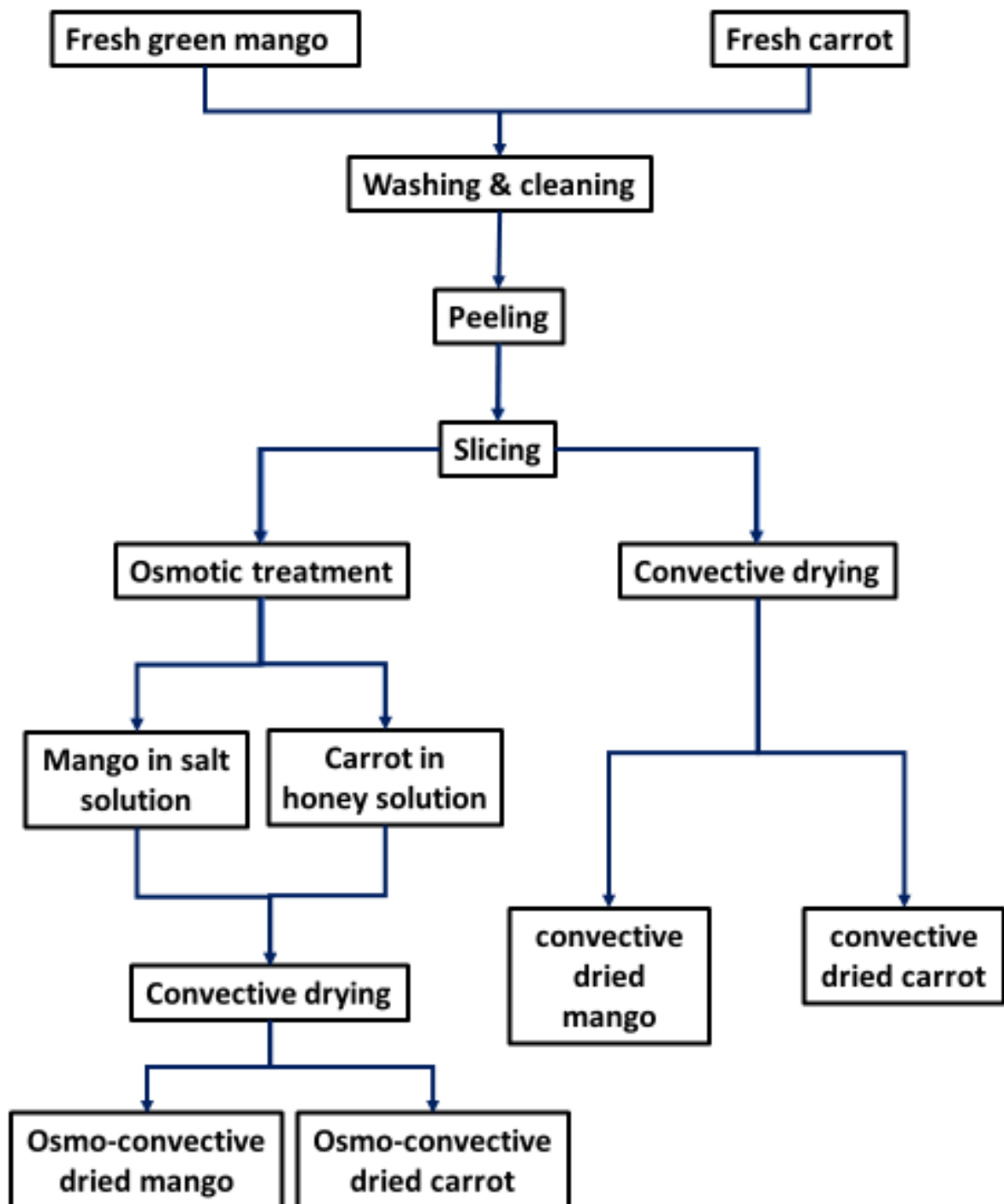


Fig: 4.1: Process flow diagram of convective and osmo-convective drying of mango and carrot

4.4 CONVECTIVE DRYING

Convective drying of the samples without osmotic treatment and with osmotic treatment was carried out in micro oven assisted convective dryer. The samples were placed in one layer on a tray and dried at 110 °C for 180 min.

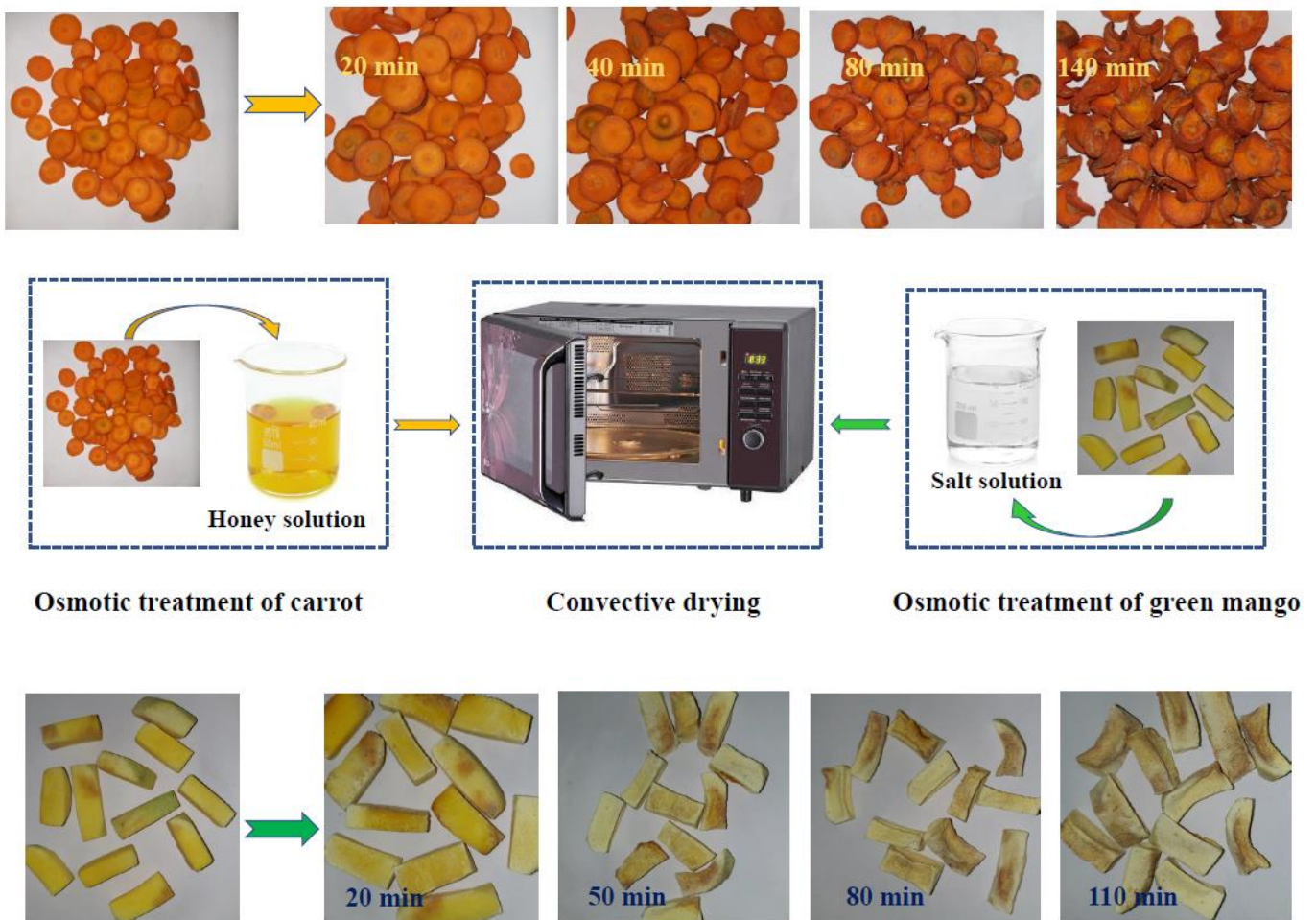


Fig: 4.2: Experimental setup for osmo-convective drying of green mangoes and carrots

4.5 QUALITY EVALUTION

All the sample including before and after osmotic treatment and the dehydrated product quality was evaluated in Scientific Food Testing Services Pvt Ltd. (13.07 °N, 80.15 °E). The different testing was carried out by using specific method to determine the moisture and nutritive parameters for mango and carrot samples. All the testing methods are listed below,

Table 4.1: Test methods applied for quality evaluation

Sl no.	Test parameters	Test method
1.	Moisture	FSSAI Lab Manual, Fruits & Veg Products 4.1
2.	Fat	SFTS/FCL/SOP/003 Issue No: 01 Issue date: 03.01.2015
3.	Crude Fiber	IS 10226 (Part-1)
4.	Protein	SFTS/FCL/SOP/002 Issue No: 01 Issue date: 03.01.2015
5.	Carbohydrates	IS 1656
6.	Energy	Food Energy Method of analysis and Conversion Factor (FAO)

4.6 DRYING CHARACTERISTICS

4.6.1 Moisture content

The moisture content of fresh and osmotically dehydrated green mango and carrot samples was determined using the AOAC (1984) method. It was obtained by taking a small amount sample and estimating the moisture content by recording the weights using the equation below,

$$\% \text{ moisture content} = \frac{W_1 - W_2}{W_2} \times 100 \quad (1)$$

Where, W_1 and W_2 indicates mass of original sample and dry sample.

4.6.2 Drying rate

The moisture content of this study was analysed to determine the amount of moisture lost from a sample of green mango and carrot over a specific

time interval. The drying rate of the samples was calculated using the mass balance equation,

$$R = \frac{WML (Kg)}{Time\ interval\ (min) \times DM\ (Kg)} \quad (2)$$

Where, WML signifies [Initial weight of sample – Weight of sample after time (t)] and DM implies Dry material.

4.6.3 Water content

The following equation is used to estimate the water content of green mango and carrot during dehydration at a specific temperature,

$$Watr\ content\ (d.b) = \frac{W_1 - W_2}{W_2} \times \frac{Kg\ water}{Kg\ DM} \quad (3)$$

CHAPTER-5

RESULT AND DISCUSSIONS

5.1 DRYING CHARACTERISTICS

5.1.1 Effect of moisture % of convective and osmo-convective drying

The variation of moisture % with time for green mango is duplicates in Figure 5.3. It has been found that the initial moisture content in green mango was 75%. After osmotic treatment the moisture content reduction was 5.2%. In case of convective drying moisture removed up to 2% in 120 min. However, in osmo-convective drying 1.6% sample moisture left after drying within 110 min.

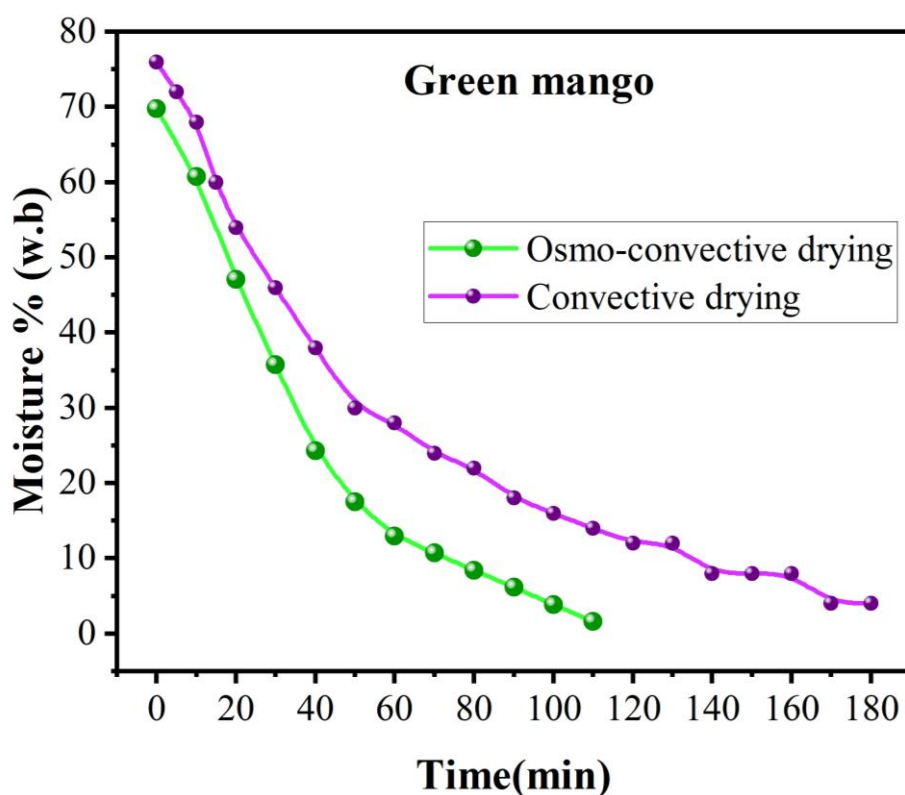


Fig 5.1: Moisture % (w.b) during osmo-convective drying and convective drying for green mango

On the other hand, moisture % during convective and osmo-convective drying is displays in Figure 5.3. Initial moisture content in carrot was tested 88 %. Whereas, after osmotic dehydration in honey solution the moisture content reduction was 5 %. In convective drying moisture removed up to 2 % in 160 min. Nevertheless,

in osmo-convective drying 0.5 % sample moisture remain after drying within 140 min. In comparison to direct convective drying, osmotic pre-treatments reduced the rates of complementary convective drying and increased the total dehydration time.

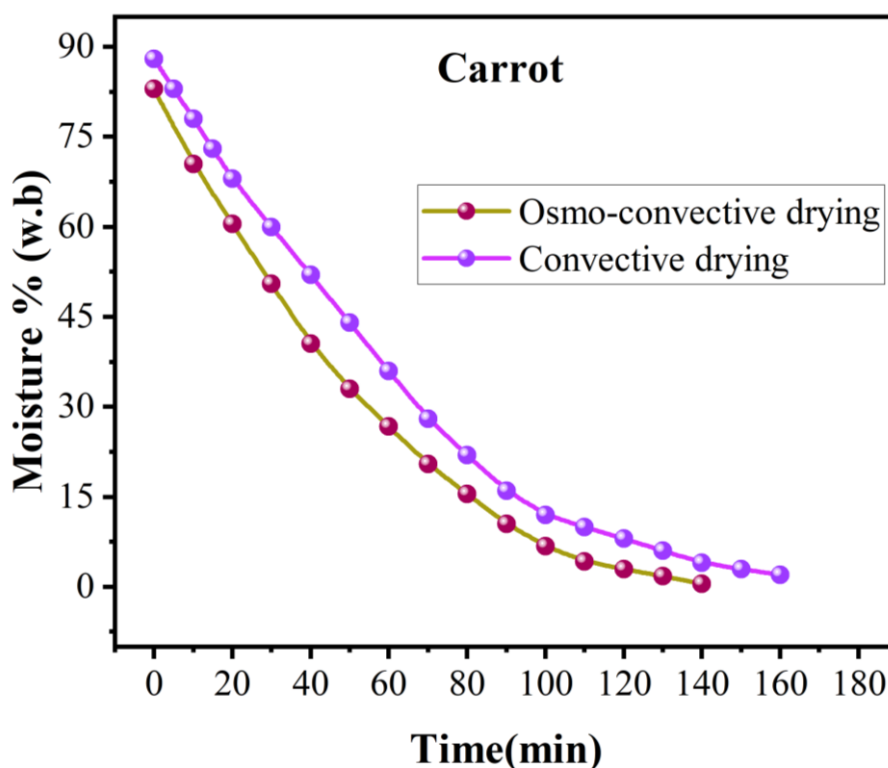


Fig: 5.2: Moisture % (w.b) during osmo-convective drying and convective drying for carrot

5.1.2 Drying rate curve for convective and osmo-convective drying

The weight of green mango slices was determined after a subsequent time interval. The drying rate at different time was evaluated by using water content, amount of moisture removed and the drying rate equation. Here, the drying rate curve was plotted against water content [Kg water/Kg DM] represented in Figure 5.5. From the drying rate curve, it can be justified that the green mango pieces were dried in falling rate period. The constant rate period was unidentified for both the convective and osmo-convective drying. Falling rate period drying implies that the internal mass transfer was done by diffusion.

Similarly, the weight of carrot slices was evaluated after a regular time interval. From the drying rate curve in Figure 5.6, it can be justified that the carrot pieces were dried in falling rate period. Again, the constant rate period was unidentified for both the convective and osmo-convective drying of carrots.

Moreover, falling rate period drying implies that the internal mass transfer was done by diffusion.

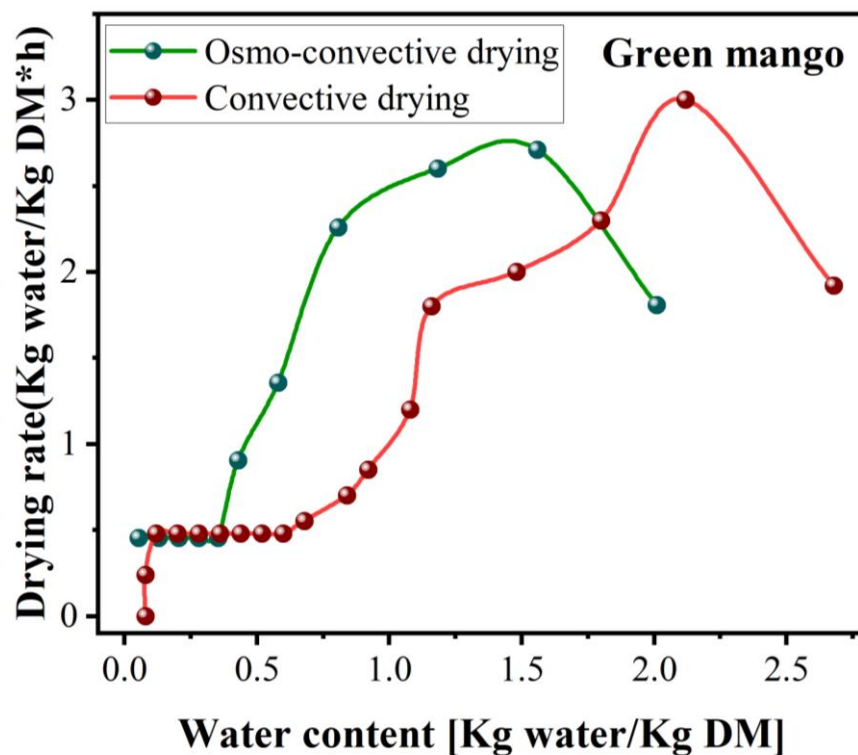


Fig: 5.3: Osmo-convective and convective drying rate curve for green mango

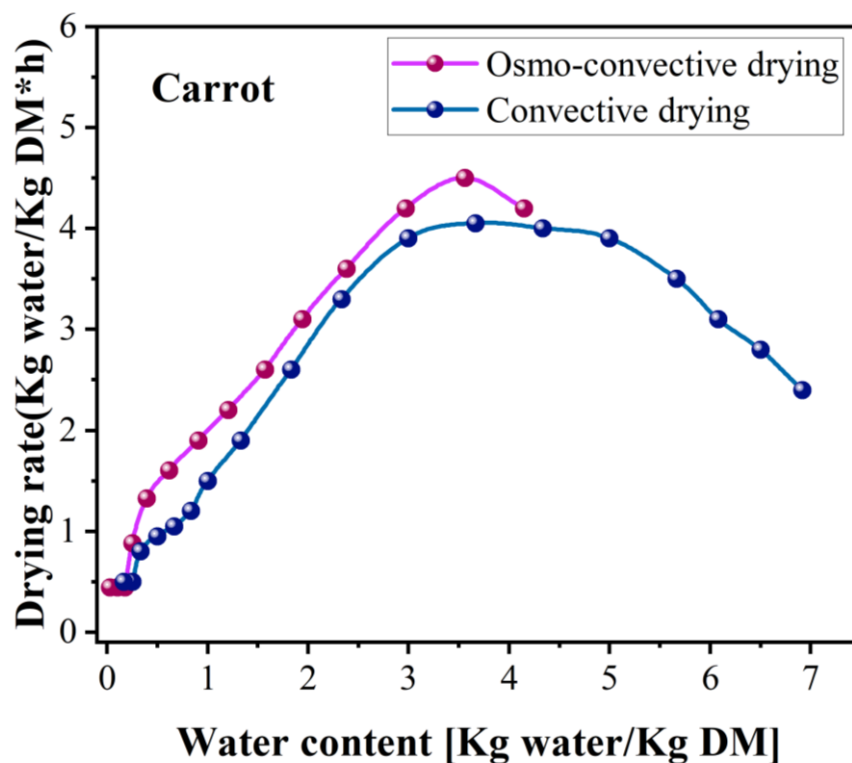


Fig: 5.4: Osmo-convective and convective drying rate curve for carrot

5.1.3 Drying curve for convective and osmo-convective drying

The drying curve of green mango for convective and osmo-convective drying are presented in Figure 5.7. It shows the water content in the sample decrease with increase in the initial time period and slow down after a certain time and lastly approached almost constant. For convective drying the water content reached almost constant of 0.08 Kg Water/Kg DM at 180min. On the other hand, in osmo-convective drying the water content was 0.053 Kg Water/Kg DM in 110min.

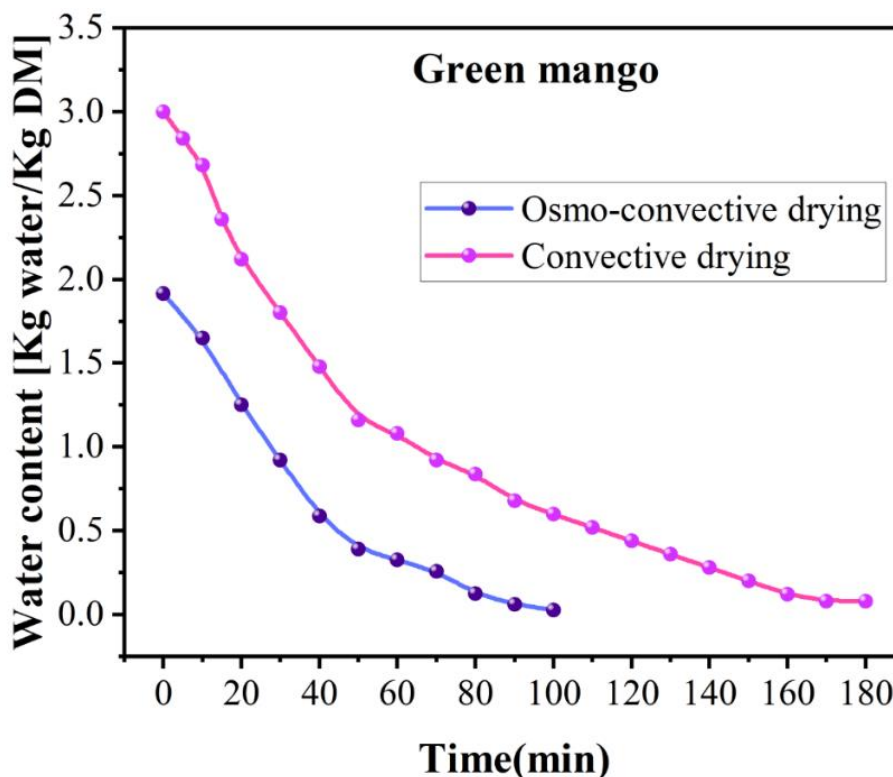


Fig: 5.5: Osmo-convective and convective drying curve for green mango

Again, the drying curve of carrot for convective and osmo-convective drying are shown in Figure 5.8. It also displays the water content in the sample decrease with increase in the initial time period. After a certain time, the moisture removal was slow down and lastly approached almost constant. For convective drying the water content reached almost constant of 0.166 Kg Water/Kg DM at 160min. However, in osmo-convective drying the water content was 0.029 Kg Water/Kg DM in 140min.

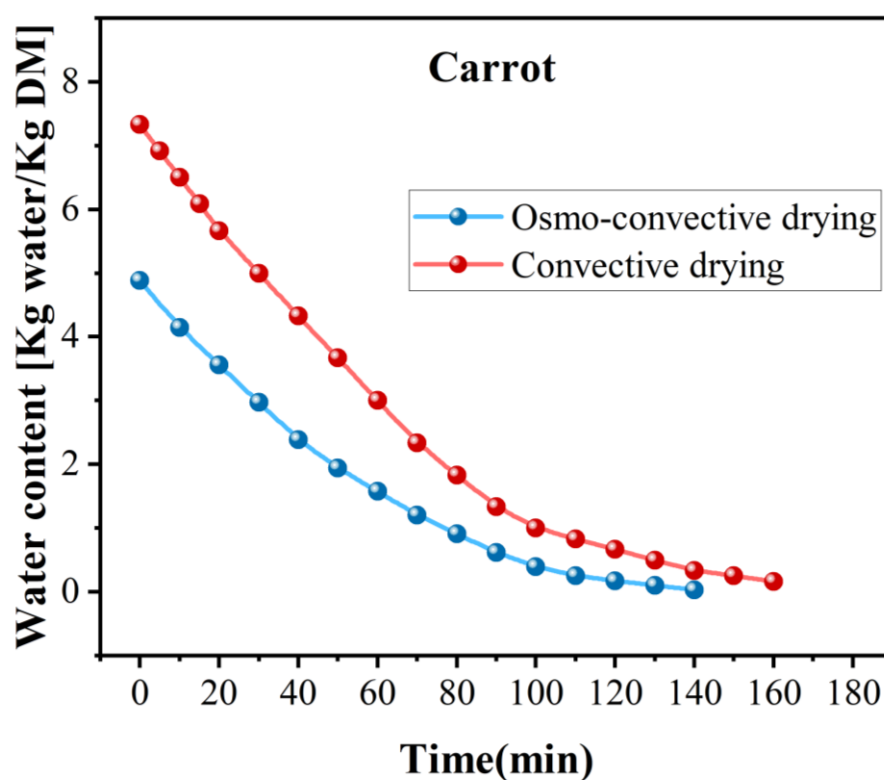


Fig: 5.6: Osmo-convective and convective drying curve for carrot

5.2 NUTRITION VALUE ANALYSIS

In general, the retention of ascorbic acid is used to gauge the overall nutritional quality of processed foods. Due to its high water solubility, sensitivity to heat, and oxidation state, this nutrient is quite prone to degradation⁶¹. The nutritional value of osmo-convective dried mango and carrot were evaluated by measuring different nutrient constituent viz. Fat, Crude Fiber, Protein, Carbohydrates and energy. According to USAD the nutritional quality of fresh mango compared with the osmo-convective dried products. It is represented in Table 5.1. It has been shown that all the nutrients value of processed product remains almost unchanged or increased. Therefore, it could be help to meet the normal vegetable diet. In fresh mango, the value of Fat and Crude Fiber was found 0.4 and 0.94 g/100g. Whereas, 17.5% of Fat, 18.1% of Crude Fiber increased in osmo-convective dried mango. Moreover, Protein and Carbohydrate content of processed mango was increased by 2 and 4.1 times as compared to the fresh samples. Again, the energy content in the samples after osmotically dehydrated samples was 260 Kcal/100g, which is significantly more than the same quantity of fresh mango (0.6 Kcal/100g).

Table 5.1: Nutritive value of fresh and osmo-convective dried mango

Sl no.	Nutrients	Fresh green mango	Osmo-convective dried mango	Unit
1.	Fat	0.40	0.47	g/100g
2.	Crude Fiber	0.94	1.11	g/100g
3.	Protein	0.82	1.64	g/100g
4.	Carbohydrates	15	62.3	g/100g
5.	Energy	0.60	260	Kcal/100g

Table 5.2: Nutritive value of fresh and osmo-convective dried carrot

Sl no.	Nutrients	Fresh carrot	Osmo-convective dried Carrot	Unit
1.	Fat	0.2	0.26	g/100g
2.	Crude Fiber	1.2	1.94	g/100g
3.	Protein	0.9	2.50	g/100g
4.	Carbohydrates	10	59.9	g/100g
5.	Energy	0.41	252	Kcal/100g

The composition of the carrot before and after osmo- convective dehydration is listed in Table 5.2. The nutritional quantity of the processed carrots was also increased than fresh carrots. It has been observed that the carrots after drying contains 0.26 g/100 g of Fat and 1.94 g/100 g of Crude Fiber, which is 30 and 74 % more than fresh carrots. Additionally, the processed samples had 2.78 and 5.99 % increases in protein (2.50 g/100 g) and carbohydrates (59.9 g/100 g), respectively,

compared to the fresh samples. The carrots in fresh condition had 0.41 kcal/ 100 g energy. However, the energy in carrots after osmo-convective drying increased to 252 Kcal/100 g. This results for both mangoes and carrots cleared that osmo-convective drying is a useful technique for preservation without altering the quality of the nutrients.

CHAPTER-6

CONCLUSION

Osmotic dehydration is a quick and efficient method for treating and preserving mangoes and carrots for long-term storage. In this research work, osmotic solution of salt and honey were used for green mangoes and carrots respectively, followed by dried in a micro wave assisted convective dryer. The quality and nutritional value of the food product were also evaluated by various testing (Moisture, Fat, Crude Fiber, Protein, Carbohydrates and Energy) and experimental results. Both the convective and osmo-convective data of green mango and carrot from the experiment used to plot the moisture% curve, drying rate curve, and drying curve. For mango, without osmotic dehydration the sample is dried at 110 °C for 180min, whereas in osmo-convective drying it was only 110 min. Again, for carrot, convective drying required 160 min and osmo-convective drying is completed within 140 min. Therefore, osmo-convective drying enhances the cost effectiveness by utilizing less energy than convective drying. Moreover, osmotically dried significantly increased the nutritional quality of the fresh samples of green mangoes and carrots. Overall the osmo-convective drying using salt and honey solution is most suitable for commercial purpose to preserved mangoes and carrots for off-season. Therefore, this method could be applied to other vegetables and fruits for extending shelf life for the preservation.

REFERENCE

1. Bellary, A. N., Sowbhagya, H. B. & Rastogi, N. K. Osmotic dehydration assisted impregnation of curcuminoids in coconut slices. *J. Food Eng.* **105**, 453–459 (2011).
2. Ramya, V. & Jain, N. K. A Review on Osmotic Dehydration of Fruits and Vegetables: An Integrated Approach. *J. Food Process Eng.* **40**, 1–22 (2017).
3. Singh, V., Hedayetullah, M., Zaman, P. & Meher, J. Postharvest Technology of Fruits and Vegetables: An Overview. *J. Post-Harvest Technol.* **2**, 124–135 (2014).
4. Xu, J., Li, T., Yan, T., Chao, J. & Wang, R. Dehydration kinetics and thermodynamics of magnesium chloride hexahydrate for thermal energy storage. *Sol. Energy Mater. Sol. Cells* **219**, 110819 (2021).
5. Gatea, A. A. Design and construction of a solar drying system , a cylindrical section and analysis of the performance of the thermal drying system. (2018) doi:10.5897/AJAR10.347.
6. Darvishi, H., Zarein, M., Minaei, S. & Khafajeh, H. Exergy and energy analysis, drying kinetics and mathematical modeling of white mulberry drying process. *Int. J. Food Eng.* **10**, 269–280 (2014).
7. Radhika, G. B., Satyanarayana, S. V. & Rao, D. G. Mathematical model on thin layer drying of finger millet (*Eluesine coracana*). *Adv. J. Food Sci. Technol.* **3**, 127–131 (2011).
8. Vijayavenkataraman, S., Iniyan, S. & Goic, R. A review of solar drying technologies. *Renew. Sustain. Energy Rev.* **16**, 2652–2670 (2012).
9. Umeshtoshniwal, S. & Karale. A review paper on Solar Dryer 1*UmeshToshniwal and 2 S.R Karale. *Int. J. Eng. Res. Appl.* **3**, 896–902 (2013).
10. Morales-Delgado, D. Y. *et al.* Effect of convective drying on total anthocyanin content, antioxidant activity and cell morphometric parameters of strawberry parenchymal tissue (*fragaria x ananassa* Dutch). *Rev. Mex. Ing. Quim.* **13**,

179–187 (2014).

11. Kaushal, P. & Sharma, H. K. Osmo-convective dehydration kinetics of jackfruit (*Artocarpus heterophyllus*). *J. Saudi Soc. Agric. Sci.* **15**, 118–126 (2016).
12. Velickova, E. & Winkelhausen, E. Physical and sensory properties of ready to eat apple chips produced by osmo-convective drying. **51**, 3691–3701 (2014).
13. Kahyaoglu, L. N., Sahin, S. & Sumnu, G. Spouted bed and microwave-assisted spouted bed drying of parboiled wheat. *Food Bioprod. Process.* **90**, 301–308 (2012).
14. Bórquez, R., Melo, D. & Saavedra, C. Microwave–Vacuum Drying of Strawberries with Automatic Temperature Control. *Food Bioprocess Technol.* **8**, 266–276 (2015).
15. Prosapio, V., Norton, I. & De Marco, I. Optimization of freeze-drying using a Life Cycle Assessment approach: Strawberries' case study. *J. Clean. Prod.* **168**, 1171–1179 (2017).
16. Harnkarnsujarit, N. & Charoenrein, S. Influence of collapsed structure on stability of β -carotene in freeze-dried mangoes. *Food Res. Int.* **44**, 3188–3194 (2011).
17. Musielak, G., Mierzwa, D. & Kroehnke, J. Trends in Food Science & Technology Food drying enhancement by ultrasound e A review. *Trends Food Sci. Technol.* **56**, 126–141 (2016).
18. Schössler, K., Jäger, H. & Knorr, D. Novel contact ultrasound system for the accelerated freeze-drying of vegetables. *Innov. Food Sci. Emerg. Technol.* **16**, 113–120 (2012).
19. Abbasi, S. & Azari, S. Original article Novel microwave – freeze drying of onion slices. 974–979 (2009) doi:10.1111/j.1365-2621.2008.01774.x.
20. Jiang, H., Zhang, M. & Mujumdar, A. S. Physico-chemical changes during different stages of MFD / FD banana chips. *J. Food Eng.* **101**, 140–145 (2010).

21. Alfaifi, B. *et al.* Radio frequency disinfestation treatments for dried fruit : Model development and validation. *J. Food Eng.* **120**, 268–276 (2014).
22. Esehaghbeygi, A. & Basiry, M. Electrohydrodynamic (EHD) drying of tomato slices (*Lycopersicon esculentum*). *J. Food Eng.* **104**, 628–631 (2011).
23. Ñ, M. P. & Cun, U. An analytical solution of population balance equations for continuous fluidized bed drying. **66**, 1916–1922 (2011).
24. Jaiboon, P., Prachayawarakorn, S., Devahastin, S. & Tungtrakul, P. Effect of high-temperature fluidized-bed drying on cooking , textural and digestive properties of waxy rice. *J. Food Eng.* **105**, 89–97 (2011).
25. Lozano-acevedo, A., Jimenez-fernández, M. & Ragazzo-sánchez, A. Fluidized Bed Drying Process of Thinly Sliced Potato (*Solanum tuberosum*). 360–366 (2011) doi:10.1007/s12230-011-9201-8.
26. Sa-adchom, P., Swasdisevi, T., Nathakaranakule, A. & Soponronnarit, S. Drying kinetics using superheated steam and quality attributes of dried pork slices for different thickness , seasoning and fibers distribution. *J. Food Eng.* **104**, 105–113 (2011).
27. Meziane, S. Drying kinetics of olive pomace in a fluidized bed dryer. *Energy Convers. Manag.* **52**, 1644–1649 (2011).
28. Vega-Mercado, H., Marcela Góngora-Nieto, M. & Barbosa-Cánovas, G. V. Advances in dehydration of foods. *J. Food Eng.* **49**, 271–289 (2001).
29. Lewicki, P. P. & Lenart, A. Osmotic Dehydration of Fruits and Vegetables. *Handb. Ind. Dry.* **7**, 691–713 (2020).
30. Wang, W. *et al.* Extraction and purification of pedunculoside from the dried barks of *Ilex rotunda* using crystallization combined with polyamide column chromatography. *Sep. Sci. Technol.* **56**, 1710–1720 (2021).
31. Ahmed, I., Qazi, I. M. & Jamal, S. Developments in osmotic dehydration technique for the preservation of fruits and vegetables. *Innov. Food Sci. Emerg. Technol.* **34**, 29–43 (2016).

32. Chandra, S. & Kumari, D. Recent Development in Osmotic Dehydration of Fruit and Vegetables : A Review Recent Development in Osmotic Dehydration of Fruit and Vegetables : **8398**, (2015).
33. Alzamora, S. M., Salvatori, D., Welti-chanes, J. & Fito, P. Novel functional foods from vegetable matrices impregnated with biologically active compounds. **67**, 205–214 (2005).
34. Solanke, S., Deshmukh, S. & Patil, B. N. Development of osmo-convective drying of sweet orange slices by using different osmotic agents. **6**, 838–842 (2018).
35. Bal, L. M., Kar, A., Satya, S. & Naik, S. N. Drying kinetics and effective moisture diffusivity of bamboo shoot slices undergoing microwave drying. *Int. J. Food Sci. Technol.* **45**, 2321–2328 (2010).
36. Tadesse, T. F., Abera, S. & Worku, S. Nutritional and Sensory Properties of Solar-Dried Carrot Slices as Affected by Blanching and Osmotic Pre-Treatments. (2015) doi:10.5923/j.food.20150501.04.
37. Wadso, L. Effect of long-term storage and blanching pre-treatments on the osmotic dehydration kinetics of carrots (*Daucus carota* L . cv . Nerac). **81**, 313–317 (2007).
38. Sunjka, P. S. & Raghavan, V. G. S. Assessment of pretreatment methods and osmotic dehydration for cranberries. (2014).
39. BOLIN, H. R., HUXSOLL, C. C., JACKSON, R. & NG, K. C. Effect of Osmotic Agents and Concentration on Fruit Quality. *J. Food Sci.* **48**, 202–205 (1983).
40. Shinde, B. & Ramaswamy, H. S. Maltodextrin Moderated Microwave Osmotic Dehydration of Mango Cubes with Finish Air-Drying: Optimum Considerations. *J. Compos. Sci.* **6**, (2022).
41. Ma, Y. *et al.* Understanding of osmotic dehydration on mass transfer and physical properties of freeze-dried apple slices: A comparative study of five saccharides osmotic agents. *J. Food Process. Preserv.* **46**, 1–10 (2022).
42. Achras, L. *et al.* Optimization of Osmotic Dehydration of Sapodilla. (2022).

43. Zongo, A., Khalloufi, S. & Mikhaylin, S. Pulsed Electric Field and Freeze-Thawing Pretreatments for Sugar Uptake Modulation during Osmotic Dehydration of Mango. (2022).
44. Dehydration, O., Kinetics, D., Attributes, Q. & Storage, F. Osmotic Dehydration , Drying Kinetics , and Quality Attributes. (2022).
45. MiniReview Factors affecting mass transfer during osmotic dehydration of fruits. **19**, 7–18 (2012).
46. Mundada, M., Hathan, B. S. & Maske, S. Mass Transfer Kinetics during Osmotic Dehydration of Pomegranate Arils. doi:10.1111/j.1750-3841.2010.01921.x.
47. Moreira, R. Ã., Chenlo, F., Torres, M. D. & Va, G. Effect of stirring in the osmotic dehydration of chestnut using glycerol solutions. **40**, 1507–1514 (2007).
48. Tortoe, C. A review of osmodehydration for food industry. *African J. Food Sci.* **4**, 303–324 (2010).
49. Shukla, B. D. & Singh, S. P. Osmo-convective drying of cauliflower, mushroom and greenpea. *J. Food Eng.* **80**, 741–747 (2007).
50. Verma, R. C., Nagajjanavar, K. & Yadachi, S. Osmo-convective drying characteristics of sapota (Chikko) slices. **11**, 959–969 (2022).
51. Solanke, S., Deshmukh, S. & Patil, B. N. Development of osmo-convective drying of sweet orange slices by using different osmotic agents. *Int. J. Chem. Stud.* **6**, 838–842 (2018).
52. Perussello, C. A., Kumar, C., De Castilhos, F. & Karim, M. A. Heat and mass transfer modeling of the osmo-convective drying of yacon roots (*Smallanthus sonchifolius*). *Appl. Therm. Eng.* **63**, 23–32 (2014).
53. Singh, B., Sharma, H. K. & Kaur, R. Storage stability of osmo-convective dried beetroot candy. **9**, 2704–2708 (2020).
54. Nsonzi, F. & Ramaswamy, H. S. Quality evaluation of osmo-convective dried

- blueberries. *Dry. Technol.* **16**, 705–723 (1998).
55. Singh, S. K. & Gangwar, V. Drying Behavior of Osmo-convective Drying of Carrot Slices and Quality Characteristics of Dehydrated Products. *Int. J. Curr. Microbiol. Appl. Sci.* **9**, 1424–1431 (2020).
 56. Yadav, A. K. & Singh, S. V. Osmotic dehydration of fruits and vegetables: a review. *J. Food Sci. Technol.* **51**, 1654–1673 (2014).
 57. Rastogi, N. K., Raghavarao, K. S. M. S., Niranjana, K. & Knorr, D. Recent developments in osmotic dehydration: methods to enhance mass transfer. **13**, 48–59 (2002).
 58. Pimentel, S. *et al.* Effect of reconditioning and reuse of sucrose syrup in quality properties and retention of nutrients in osmotic dehydration of guava. *Dry. Technol.* **34**, 997–1008 (2016).
 59. Bellary, A. N. & Rastogi, N. K. Effect of hypotonic and hypertonic solutions on impregnation of curcuminoids in coconut slices. *Innov. Food Sci. Emerg. Technol.* **16**, 33–40 (2012).
 60. Kaur, K., Kumar, S. & Alam, S. Air drying kinetics and quality characteristics of oyster mushroom (*Pleurotus ostreatus*) influenced by osmotic dehydration. **16**, 214–222 (2014).
 61. Values, N. Impact of Three Different Dehydration Methods on. (2020).