DEVELOPMENT AND PERFORMANCE EVALUATION OF INFRARED DRYER

By,

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TAVANUR, MALAPPURAM – 679573

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PROJECT REPORT

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
TAVANUR, MALAPPURAM-679573
KERALA, INDIA
2020

DECLARATION

We hereby declare that this thesis entitled **"DEVELOPMENT AND PERFORMANCE EVALUATION OF INFRARED DRYER"** is a bonafide record of research work done by us during the course of academic programme in the Kerala Agricultural University and the thesis has not previously formed for the award of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this project report entitled **"DEVELOPMENT AND PERFORMANCE EVALUATION OF INFRARED DRYER"** is a record of project work done jointly by Mr. Anuj Sonal P, Mr. Aswin Jayaraj, Ms. Shahana A, Ms. Shreya Khalai, and Ms. Athulya Murali under my guidance and supervision and that it has not previously formed the basis for any degree, diploma, fellowship or associateship or other similar title of another University or Society.

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DEDICATED TO ALL FOOD ENGINEERS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

SYMBOLS AND ABBREVIATIONS

% : Per cent

& : And

/ : Per

<: Less than

±: Plus or minus sign

◦: Degree

°C: Degree centigrade

a***:** Greenness or redness

b* **:**Blueness or yellowness

b**:** Breadth

cm: Centimetre

db **:**Dry basis

et al.: And others

etc. **:** Etcetera

Fig.**:** Figure

g **:** Gram

h: hour

ha: hectare

HP: Horse power

KCAET: Kelappaji College of Agricultural Engineering and Technology

kg**:** Kilogram

kJ**:** Kilo Joule

Kwh **:** Kilo watt hour

L **:** Length

L***:** Lightness or darkness

min: Minute

ml**:** Milliliter

mm**:** Millimeter

No.**:** Number

pH**:** Percentage of H+ ions

rpm**:** Revolutions per minute

s **:** Second

SS: Stainless Steel

t: Temperature

TV: True Volume

V**:** Volt

viz **:** Namely

W**:** Watt

wb**:** Wet basis

μ: Coefficient of friction

ρ: True density

ρ_b: Bulk density

INTRODUCTION

CHAPTER I

INTRODUCTION

Fruits and vegetables are an important supplement to the human diet as they provide essential minerals, vitamins and fibre required for maintaining health. The varied agro climatic conditions available in our country make it possible for us to produce several types of tropical, subtropical and temperate fruits and vegetables. Globally, India stands second position in the production of fruits and vegetables after China. The fruits and vegetable production in India during 2017-18 was 97.35 MT and 187.5 MT, respectively. In Kerala, fresh fruits represent 34.06% area of food crops during the agricultural year 2017-18**.** The important fresh fruits and vegetables cultivated in Kerala are jack, mango, banana, plantain, pineapple, papaya, tomato, drumstick, amaranthus, bitter gourd, snake gourd, brinjal, etc. The fruits and vegetable production in Kerala during 2017-18 were 6.7 lakh tonnes and 0.95 lakh tonnes, respectively. The total area of fresh fruits and vegetable cultivation during the year 2017-18 were 3.3 lakh ha and 0.46 lakh ha, respectively. Vegetables represent 4.81% area of total food crops. (Agricultural Statistics 2017-18, Govt of Kerala). Fruits and vegetables are highly perishable commodities and the ambient high temperature obtained in the tropical country like ours makes them more susceptible for rapid development of senescence, decay and rotting. Both respiration and transpiration rates in agricultural produce are proportional to temperature rise, which result in spoilage, unless properly preserved.

Fruits and vegetables include a diverse group of plant foods that vary greatly in content of energy and nutrients. Diets high in fruits and vegetables are widely recommended for their health-promoting properties. Additionally, fruits and vegetables supply dietary fibre and the fibre intake is linked to lower incidence of cardiovascular disease and obesity. Fruits and vegetables supply vitamins, minerals and phytochemicals to the diet that function as antioxidants, phytoestrogens, anti-inflammatory agents and other protective mechanisms.

Carrot (*Daucus carota* subsp. *sativus*) is a root vegetable, usually orange in colour, though purple, black, red, white, and yellow cultivars exist. They are a domesticated form of the wild carrot, *Daucus carota*, native to Europe and South-western Asia. The plant probably originated in Persia and was originally cultivated for its leaves and seeds. The roots contain high quantities of alpha- and beta-carotene, and are a good source of vitamin K and vitamin B6.

Table 1.1. Carrot Production in India during the year 2017-18

Sl No:	State	Production (000 tonnes)	Share (%)
1	Haryana	445.99	27.4
2	Punjab	197.17	12.12
3	Uttar Pradesh	160.85	9.89
4	Bihar	147.45	9.07
5	Madhya Pradesh	138.96	8.54
6	Tamil Nadu	107.30	6.60
7	Karnataka	101.52	6.24
8	Assam	63.77	3.92
9	Telengana	61.45	3.78
10	Jammu & Kashmir	32.41	1.99
	Total	**1456.87**	

Source: National Horticultural Board (NHB)

Post-harvest decay is the major factor limiting the extension of shelf-life of carrots and nearly 17% of total product is deteriorated during post-harvest handling. A lot of techniques are used to minimize deterioration after harvesting. Refrigeration and controlled atmosphere storage are commonly used preservation methods (Negi & Roy, 2000). Alternatively, the keeping ability of carrot can be enhanced by drying and subsequent storage. Although higher temperature causes wilt and have a poor appearance on the carrot. Carrot can be dried to improve its shelf-life, lower shipping weights, minimize the loss of flavour and nutritional value.

Drying refers to the removal of moisture from food products to a predetermined level. It is a thermo-physical and physico-chemical operation by which the excess moisture from the product is removed. Drying makes the food products suitable for safe storage and protects them against attack of insects, molds and other microorganisms during storage. During drying, the moisture from solids gets vapourized and diffused in dilute environment (Sahay and Singh, 1994). Various drying methods are employed to reduce the moisture content of agricultural produce.

Freeze drying of biological materials is one of the best methods of water removal which results in a high quality product. Freeze drying is the method of sublimation of ice fraction where water passes from solid to gaseous state without entering liquid phase. Due to very low temperature, all the deterioration activities and microbiological activities are stopped and provide better quality to the final product. At present, the market for organic products is increasing. Therefore, the use of freeze drying of fruits and vegetables is not only increasing in volume but also diversifying (Brown 1999). Freeze drying seems to be better preservation method over other dehydration methods such as convective drying, contact drying etc. (Hsuch et al. 2003). Freeze drying of small fruits (strawberry) received particular attention by several researchers (Paakkonen and Mattila 1991, Hammami and Rene 1997, Shishegarha et al. 2002). Strawberry dried at 20°C retained better quality than at 60°C. The product mostly collapses i.e. loss in structure, reduction in pore size and shrinkage at higher temperature (Hammami and Rene 1997). Paakkonen and Mattila (1991) have found that low processing temperature improved the sensory quality of dried fruits.

Vacuum drying is an important process for heat sensitive materials. It is a drying method in which the object to be dried is placed in an enclosed container and vacuum is created to reduce the chamber pressure below the vapour pressure of water, causing it to boil. A vacuum pump is employed to reduce the pressure around the substance to be dried. The vacuum drying forces the pressure in the narrow gaps and in the tubes to decrease, which enables the moisture in the gaps to evaporate faster. In addition, moisture trapped in the narrow gaps by bumping phenomenon could blow out, unless the temperature inside the drying object drops excessively, which further expedites drying. Therefore, using a pump with a volume sufficient for venting evaporated moisture for vacuum drying enables any porous or even powder-like object to be dried thoroughly even from the inside uniformly. A comparison of drying technologies in review by Khin et al. (2005) showed that freeze drying, vacuum drying and osmotic dehydration are considered too costly for large scale production of commodity.

Fluidized bed dryer has wide applications in industries- food, fine chemicals and pharmaceuticals. They provide an effective method of drying for relatively free flowing particles with a reasonable narrow particle size distribution. The feed may take the form of powders, granules, crystals, seeds and non-friable agglomerates. Fluidized bed dryers can process a wide variation of feed rates from pounds to several hundred tonnes per hour. Two types of fluidized bed dryers exist. The first type is referred to as a static fluid bed because the dryer remains stationary during operation. Static fluidized bed dryer can be continuous or batch-type and may be round or rectangular. The second type of fluidized bed dryers is a vibrating fluidized bed dryer where the body of the dryer vibrates or oscillates, assisting the movement of material through the unit. Vibrating fluidized bed dryers are almost exclusively rectangular in shape. Fluidized bed dryers are extensively used in particular solids drying because of their high rates of heat and mass transfer and the reduced drying times.

The quality parameters of carrot are of paramount consideration during the employment of different drying mechanisms (Chou & Chua, 2001). Various methods of drying have been developed for solids, and each method of drying has its own advantages and disadvantages. Sun drying being the most common method used to preserve agricultural products is extremely weather dependent, and has the problems of contamination with dust, soil, sand particles and insects. Hot air drying of foods is of low energy efficiency and has long drying time during falling rate period. Because of the low thermal conductivity of food materials in this period, heat transfer of food during conventional heating is limited. The desire to eliminate this problem, to prevent significant quality loss, and to achieve fast and effective thermal processing, has resulted in the increased use of other techniques such as microwave and infrared drying.

Infrared drying has gained popularity as an alternative drying method for agricultural products. Infrared drying offers many advantages over conventional drying under similar drying conditions. When infrared radiation is used to heat or dry moist materials, the radiations impinge the exposed material, penetrate through it and the energy of radiation converts into the heat (Hebbar& Rostagi, 2001). Infrared drying has been investigated as a potential method for obtaining high quality dried foodstuffs, including fruits, vegetables and grains (Abe & Afzal, 1997; Afzal & Abe, 1998, 2000; Hebbar & Rostagi, 2001; Zhu, Zou, Chu, & Li, 2002).

Considering the above facts, a study had been undertaken on **“Development and Performance Evaluation of Infrared Dryer”** with the following objectives:

1. To study the engineering properties of carrot
2. To develop an infrared dryer
3. To conduct the performance evaluation of infrared dryer in terms of dryer efficiency and quality of dried carrot

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

This chapter deals with comprehensive review of the research work done by various research workers related to drying, methods of drying, infrared drying, types of dryers, engineering properties of carrot etc.

2.1. Drying

Fruits, vegetables, and their products in the dried form are good sources of energy, minerals, and vitamins. However, during the process of drying, there are changes in quality parameters of products. The extent of the changes depends on the care taken in preparing the material before drying and on the drying process used. Major quality parameters associated with dried food products are colour; visual appeal; shape; flavour; microbial load; retention of nutrients; porosity-bulk density; texture; rehydration properties; water activity; freedom from pests, insects, and other contaminants; preservatives; and freedom from taints and off-odours (Shyam Sablani, 2006)

Drying is one of the oldest preservation processes available to the mankind, on that we can track since prehistoric times. In today's food market, dried foods play an important role in the food supply chain. It is estimated that fruits and vegetables constitute about 1% of the total dried foods in the food industry. The main feature of this process consists on lowering the water content in order to avoid or slow down food spoilage by microorganisms. (Naseer Ahmed,2013)

2.1.1. Methods of Drying

Drying is the oldest method of preserving food. Throughout history, the sun, the wind, and a smoky fire were used to remove water from fruits, meats, grains and herbs. By definition, food dehydration is the process of removing water from food by circulating hot air through it, which prohibits the growth of enzymes and bacteria. Dried foods are tasty, nutritious, light-weight, easy-to- prepare, and easy-to-store and use. The energy input is less than what is needed to freeze or canning, and the storage space is minimal compared with that needed for canning jars and freeze containers. The nutritional value of food is only minimally affected by drying. Vitamin A is retained during drying; however, because vitamin A is light sensitive, food containing it should be stored in dark places. Yellow and dark green vegetables, such as peppers, carrots, winter squash, and sweet potatoes, have high vitamin A content. Vitamin C is destroyed by exposure to heat, although pre-treating foods with lemon, orange, or pineapple juice increases vitamin C content. Dried fruits and vegetables are high in fibre and carbohydrates and low in fat, making them healthy food choices (Naseer Ahmed, 2013)

2.1.1.1. Sun Drying

Sun drying is a traditional method of drying crops and grains. It is the most common and popular method of drying. Depending upon the climatic conditions, drying period varies from 2 to 3 weeks. This type of method is economical but weather dependent. It is mostly prevalent in the regions where weather is sufficiently sunny. The high sugar and acid content of fruits make them safe to dry under the sun. Vegetables and meats are not recommended for sun drying. Vegetables are low in sugar and acid. This increases the risk for food spoilage. Meats are high in protein, making them ideal for microbial growth when heat and humidity cannot be controlled. To dry under the sun, hot, dry, breezy days are the best. A minimum temperature of 86 °F is needed with higher temperatures being better. It takes several days to dry foods out-of-doors. Because the weather is uncontrollable, sun drying can be risky. Also, the high humidity prevailing in the southern region of our country is a problem. Humidity below 60 percent is best for sun drying. Often these ideal conditions are not available during drying. Fruits dried in the sun are placed on trays made of screen or wooden dowels. Screens need to be safe for contact with food. The best screens are stainless steel, teflon coated fibreglass or plastic. (Naseer Ahmed, 2013)

2.1.1.2. Solar Drying

Recent efforts to improve on sun drying have led to solar drying. Solar drying also uses the sun as the heat source. A foil surface inside the dehydrator helps to increase the temperature. Ventilation speeds up the drying time. Shorter drying times reduce the risks of food spoilage or mold growth. Solar drying of agricultural products can be advantageous alternative to sun drying for farmers of developing nations. Solar drying provides high air temperatures and lower relative humidity than sun drying. It enhances drying rates and lower final moisture content of dried products. As a result, the risk of spoilage is reduced, both during the actual drying process and in subsequent storage. The two inherent principles of solar drying include the solar heating of air and the removal of moisture from the wet material by the heated air. (Singh and Sahay, 1994).

Greenhouse drying is a method in which the product is dried in an enclosed structure having transparent walls and roofs, made up of glass, polyethylene film etc. In greenhouse drying, the product are placed in trays and the transparent cover material allows short wave solar radiation to enter and is partially opaque to the long wave radiation leading to a greenhouse effect and the moisture is removed by natural convection or forced convection. This technology improves the product quality and reduces the drying period.

2.1.1.3. Oven Drying

Oven drying generally adopts the forced circulation of hot air inside the chamber of the oven. In the drying chamber, the hot air rises above and reaches the top of the chamber. Then, hot air is circulated back to the bottom by a fan installed inside the chamber and hence, the optimum amount of heat is achieved gradually inside the oven. It facilitates the heating of the raw material placed on the trays and the wet moisture taken out from the material will sent out using an exhaust at the same time. It is commonly used to dry fruits (grapes, dates, etc.) and vegetable pieces. Depending on the food and the desired final moisture, drying time varies. When compared to other drying methods, oven drying is inexpensive and efficient. (Norhashila Hashim *et al,* 2016)

2.2 Mechanical Dryers

2.2.1 Fluidised Bed Dryer

The principle of operation of fluidised bed dryer is to provide sufficient air pressure to fluidise a thin bed of product providing excellent air contact. Above a certain pressure, related to the weight per unit area of the bed, the pressure drop across the bed becomes constant with the volume flow rate, so that fast drying can occur. The design air velocity should be equal/slightly greater than the terminal velocity of the product, so that the solid particles will be blown up and become suspended in the air stream (Sahay and Singh, 1994).

A. Reyes *et al.* (2007) used a mechanically agitated batch-type fluidized bed dryer to dry 3 kg lots of carrot slices at temperatures between 70°C and 160°C, air velocities between 1.1 m/s and 2.2 m/s and stirring rates between 30 rpm and 70 rpm. It was found that loss of carotenes is minimized and efficient drying occurred when drying was carried out at about 130ºC with a drying time below 12 minutes.

2.2.2 Vacuum Dryer

Vacuum drying is a process in which materials are dried in a reduced pressure environment, which lowers the heat needed for rapid drying. Vacuum dryers offer low temperature drying of thermolabile materials and are suitable for solvent recovery from solid products containing solvents.

Aroldo Arevalo Pinedo *et al.* (2004) studied the effect of selected pre-treatments as freezing and bleaching and process parameters as pressure and temperature on vacuum drying kinetics of carrot. The experimental runs were driven in a dryer under vacuum, at pressures of 5, 15 and 25 kPa and temperatures of 50, 60 and 70 °C. The influences on the drying kinetics of the pressure and temperature were studied, as well as effect of adopting pre-treatments. It was observed that the applied pre-treatments influence favourably in the kinetics of drying, however the freezing showed the greater influence than bleaching. Main factors affecting the drying velocity of carrot slabs were freezing pre-treatment and lower pressure of drying chamber. Water removal during drying of the carrot slabs occurred in the falling-rate period. Effective diffusivity of moisture transport during vacuum drying increased with the freezing pre-treatment and with the decrease of pressure and temperature.

2.2.3 Tray Dryer

In a tray dryer, many shallow trays are kept one above the other, with a gap in between, in the drying chamber. Tray dryer is generally used for drying vegetables and similar semi perishables. The trays may or may not have a perforated bottom. Perforated trays are used when the plenum chamber is at the bottom of the drying chamber. If the heated air is coming from the sides of the drying chamber, the trays may not have a perforated bottom. The gaps in between the group of trays permit air ventilation. Products are kept in thin layers in the trays. In tray dryer, hot air is continuously circulated. Forced convection heating takes place to remove moisture from the products placed in trays. (Sahay and Singh, 1994)

V. Sruthi *et al*, (2018) dried 50 grams of fresh carrot in a tray dryer under controlled temperature until constant weight. The water removed during the drying process was determined by periodic weighing of the samples using an analytical balance. The drying tests were conducted at temperatures of 65, 70, 75 and 80ºC. The weight at every 20 min time interval up to 140 minutes was noted. The optimized drying temperature was found to be 75º C.

2.2.4 Freeze Dryer

Freeze-drying technology refers to the method of dehydrating frozen fruits and vegetables under a vacuum. It works on the principle of sublimation; the moisture part of the foods takes a gaseous form directly from a solid state without going through the in-between liquid state. Freeze-drying method by lack of liquid water, oxygen-free environment (if operated under vacuum), and low operating temperatures is thus the best choice to dehydrate fruits and vegetables in order to keep an optimized biocompound content in the final products. Despite the long drying time and expensive process, freeze-drying is widely used to produce high-value food products due to maximal retention of food quality when compared to other drying techniques.

Freeze-drying makes use of the sublimation phenomenon (at temperatures lower than 0.01ºC, and water vapor pressures below 0.612 kPa). During freeze drying process, the removal of solid-state water (ice) occurs in three steps: (a) freezing, where the sample should be completely frozen; (b) primary drying, when ice is sublimated, usually at sub-atmospheric pressure; and (c) secondary drying, when the remaining unfrozen/bound water is desorbed from the drier food matrix. (Sagar Bhatta *et al*, 2020)

S. Litvin *et al*, (1998) conducted a study and found out that freeze drying for 2 h at a plate temperature of 30°C followed by 1.5 h at 55 °C was sufficient to remove all water by sublimation and reach a product moisture of about 40%. The partially freeze dried product was microwave treated for 50 s and then dried to 5% moisture in vacuum or forced air. The colour, dimensions and rehydration ratio of the partially freeze dried, microwave treated and air dried product were similar to same quality parameters of the product freeze dried to the final moisture content. Total freeze drying time at 30°C was 9.5 h as compared to a combination of 3.5–3.75 h of partial freeze drying followed by a short microwave treatment and 3.75 h air drying.

2.3. Infrared Drying

Infrared drying involve a heat transfer by radiation between a hot element and a material at lower temperature that needs to be heated or dried**.** The peak wavelength of the radiation is dependent of the temperature of the heated element. Thermal radiation is considered to be infrared in the electromagnetic spectrum between the end of the visible light i.e. 0,78 µm, and 1000 µm**.** Effectiveness is the capability of producing a desired result or the ability to produce desired output. IR heating effectiveness is between 80% and 90%, the emitted radiation is in narrow wavelength range and they are miniaturized (Sadin et al., 2014). IR heating has many benefits including uniform heating, low processing time, high heat transfer rate and energy consumption, and improved product quality (Zhu and Pan, 2009). In addition, IR drying found also application in various food analyses to measure water content in food products (Nowak and Lewicki, 2004). Advantages of IR radiation over convective heating include high heat transfer coefficients, short process times, and low energy costs (Ratti and Mujumdar, 1995).

Comparison of IR drying with convective drying of apple showed that drying time of the process can be shortened to about 50% when heating is done with IR energy (Nowak and Lewicki, 2004). The total energy consumption was defined as the sum of the electrical energy consumed during drying process and included the energy used to heat the air, energy to drive fan, energy to drive the conveyor, and energy used in the infrared heaters. Specific energy consumption was lower, and thermal efficiency was higher for the IR-hot air setting when compared to both IR and hot air settings (El-Mesery and Mwithiga, 2015).

IR radiation has been used in combination with several drying methods because it has advantages of increasing the drying efficiency. The drying efficiency was defined as the actual absolute humidity change over the dryer compared to the saturated absolute humidity change (Andersson, 2014). The combination of IR with hot air provides the synergistic effect, resulting in an efficient drying process (Afzal et al., 1999; Nawirska et al., 2009).

2.3.1. Advantages and Limitations of IR Drying

Many authors have pointed out the advantages and disadvantages of using IR drying (Van't Land, 1991; Hallstro¨m et al., 1988; Nonhebel and Moss, 1971; Dostie et al., 1989). In fact, IR drying has many positive attributes, the main one being the reduction in drying time. Also, IR drying offers solution to problems that seemed to be unsolvable in the past such as those associated with the carrying of volatile organic compounds from solvent-based paints by the exhaust hot air in conventional convective dryers.

Infrared drying has got a lot of advantages over conventional drying. IR radiation penetrates directly into the product without heating the surroundings and results in uniform heating of the product. It is easy to program, manipulate and control the heating cycle for different products and to be adapted to changing conditions. It helps in the levelling of the moisture profiles in the product and causes low product deterioration. IR sources are inexpensive compared to dielectric and microwave sources and have a long service life and low maintenance. It occupies little space and may easily be adapted to previously installed conventional dryers. IR drying is having some disadvantages. The testing of the equipment must be carried out in the plant to assure a successful design. Potential fire hazards must be considered in design and operation.

IR dryers may be batch or continuous type, the later is the most common arrangement. IR ovens for dryers are usually designed and constructed from standard IR sections arranged and integrated to the conventional dryers in such a way that IR radiation is directly intercepted by the product to be dried. These sections are selected on the basis of the particular application. It is desirable to test the product on a laboratory-scale IR oven under simulated conditions and to design the large-scale unit on the basis of the experimental data obtained. To accomplish a reliable design, it is also necessary to know the efficiency of conversion from electric to IR energy of the radiators used in the plant (unless gas-fired IR heaters are used). The main data required are the intensity of radiation and the residence time (Nonhebel and Moss, 1971, p. 289) but although oven style and cross section are easily determined; on the other hand, the selection of the heat source, time–temperature cycle, and the power density requires oven design experience (Fostoria, Technical Bulletin, 1992). Air flow is required in IR ovens for two primary purposes, air movement to cool and protect oven walls and terminals and to remove smoke, moisture, solvents, hazardous vapours, etc.

2.4. Carrot

Carrots (*Daucus carota* L.), among the most important root vegetables in the Apiaceae family, are cultivated worldwide. The storage root is widely utilized due to its richness in carotenoids, anthocyanins, dietary fibre, vitamins and other nutrients. Carrot extracts, which serve as sources of antioxidants, have important functions in preventing many diseases. The biosynthesis, metabolism, and medicinal properties of carotenoids in carrots have been widely studied. Research on hormone regulation in the growth and development of carrots has also been widely performed. Recently, with the development of high-throughput sequencing technology, many efficient tools have been adopted in carrot research. A large amount of sequence data has been produced and applied to improve carrot breeding. (Ahmed Khadr & Ai-Sheng Xiong, 2019)

2.4.1. Origin

The genus Daucus has many wild forms that grow mostly in the Mediterranean region and south-west Asia. Afghanistan is believed to be the primary centre of genetic diversity. There are evidences that purple carrot together with a yellow variant spread from Afghanistan to the Mediterranean region as early as the tenth or eleventh century. It is generally assumed that the eastern, purple-rooted carrot originated in Afghanistan in the region where the Himalayan and Hindu Kush mountains meet, and that it was domesticated in Afghanistan and adjacent regions of Russia, Iran, India, Pakistan and Anatolia. Purple carrot, together with a yellow variant, spread to the Mediterranean region and western Europe in the 11–14th centuries, and to China, India and Japan in the 14–17th centuries. The white and orange carrots are probably mutations of the yellow form. The domestic carrot readily crosses with widely adapted wild carrot known as Queen Anne’s lace.

2.4.2. Nutrition

Raw carrots are 88% water, 9% carbohydrates, 0.9% protein, 2.8% dietary fiber, 1% ash and 0.2% fat. Carrot dietary fibre comprises mostly cellulose, with smaller proportions of hemicellulose, lignin and starch. Free sugars in carrot include sucrose, glucose, and fructose. The carrot gets its characteristic, bright orange colour from β-carotene, and lesser amounts of αcarotene, γ-carotene, lutein, and zeaxanthin. α- and β-carotenes are partly metabolized into vitamin A, providing more than 100% of the Daily Value (DV) per 100 g serving of carrots (right table). Carrots are also a good source of vitamin K (13% DV) and vitamin B6 (11% DV), but otherwise have modest content of other essential nutrients.

Table 2.1 – Nutritional Content of Carrot

Per 100 g

Energy	41 kcal
Carbohydrates	9.58 g
Fat	0.24 g
Protein	0.93 g
Vitamin A	835 μg
Thiamine (B1)	0.066 mg
Riboflavin (B2)	0.058 mg
Niacin (B3)	0.983 mg
Pantothenic acid (B5)	0.273 mg
Vitamin B6	0.138 mg
Vitamin C	5.9 mg
Vitamin E	0.66 mg
Vitamin K	15 μg
Minerals	

Calcium	33 mg
Iron	0.3 mg
Magnesium	12 mg
Manganese	0.143 mg
Phosphorus	35 mg
Potassium	320 mg
Sodium	69 mg
Zinc	0.24 mg
Other constituents	
Water	80 g

Source: Silva Dias, *et al* (2014)

2.4.3. Production of Carrot in India

Carrot is widely grown both for fresh consumption and processing. It is among the top-ten most economically important vegetable crops in the world both in terms of acreage and market value. In 2005, the world production of carrot stood at 24 million tonnes from an area of 1.1 million hectares. The total traded carrot seed crop at global level is estimated as 100 million USD.

Carrot is cultivated on large acreage in Europe including the former USSR, America, Asia and Africa. In India estimated acreage of carrot is about 2, 00,000 ha. This speaks about the economic importance of carrot. Carrot is a rich source of high carotene content (pro-vitamin A) and reportedly has anti-carcinogenic effect due to carotene. It is the most widely grown member of the Apiaceae or Umbelliferae.

2.4.4. Soil Requirement for Carrot Farming

Carrots can be grown well in a wide variety of soils. However, the ideal soil for commercial carrot farming should be deep, loose, well-drained and rich in humus. Loamy or sandy loam soils with sufficient quantities of humus are well suited to the cultivation of carrots. The ideal pH range for obtaining good yield is 5.5-6.5. Soils with pH upto 7 can also be used, but too alkaline or acidic soils are unsuitable for this crop.

2.4.5. Climate Requirement for Carrot Farming

Carrot is a cold weather crop, and it also does well in warm climates. The optimum temperature for getting excellent growth is between 16 to 20°C, while temperatures above 28°C drastically reduce top growth. Temperatures lower than 16°C affect the development of colour and result in long slender roots, while higher temperatures produce shorter and thicker roots. The temperatures between 15 and 20°C result in attractive roots with excellent red colour and quality.

2.4.6. Harvesting of Carrot

Early carrots are harvested when they are partly developed. Carrots are harvested when the roots are about 1.8 cm or larger in diameter at the upper end. The soil may be loosened with a special plough (carrot lifter) or an ordinary plough. The field is irrigated once a day before harvesting to facilitate harvest. After harvesting, the carrots are placed in a packing house in crates before washing.

2.4.7. Yield

Carrot yield differs according to the variety. The tropical varieties yield about 25-30 tonnes per hectare in 100 to 120 days.

2.4.8. Varieties of Carrot

2.4.8.1. *Pusa Kesar*

This has been bred at Indian Agricultural Research Institute, New Delhi and is an old release of 1963. It was evolved from a cross of Local Red and Nantes. The roots are scarlet in colour. It is rich in carotene (38 mg/100 g edible portion). Roots stay longer in field without bolting. Seed production in north Indian plains is successful.

2.4.8.2 *Nantes*

This variety belongs to European or temperate types. Its seed production is possible only in the hilly areas. It is an introduction by IARI Regional Station, Katrain. The roots are half long (12-15 cm), slim, well-shaped, cylindrical with stumped end forming a small thin tail. The cortex and core are deep orange. It ranks good in quality, but the top is brittle making pulling difficult. Keeping quality is poor. It is suitable for cultivation in cooler months. It takes 110-120 days for root formation.

2.4.8.3 *Pusa Meghali*

This is a tropical or Asiatic type cultivar. It has been developed at Indian Agricultural Research Institute, New Delhi from a cross between Pusa Kesar and Nantes and was released by the Institute in 1985. It has short top, smooth roots with orange flesh and self-coloured core. It is richer in carotene content (11571 IU/100 g) than Pusa Kesar (7753 IU/100 g) and produces seeds in plains. It is suitable for early sowing and takes 110-120 days to attain harvest maturity and yields 260-280 q/ha.

2.4.8.4. *Pusa Yamdagni*

This has been developed at IARI, Regional Station, Katrain from an inter-varietal cross between EC 9981 and Nantes to combine earliness and size of root of the former and self-coloured core character of the latter. It has performed well both in the hills and plains. It is early in maturity. It has been released by the central variety release committee.

2.4.8.5. *Kuroda*

It is an old variety developed in Japan by Mr. Kuroda but is very popular in Indian seed companies for large scale sales. It has long, sweet, tender orange colour roots with wide shoulders. Roots are tapering to a blunt point. Roots are smooth, uniform, and conical in shape. Roots have better storability.

2.4.9. Consumption

Carrots can be eaten in a variety of ways. Only 3 percent of the β-carotene in raw carrots is released during digestion: this can be improved to 39% by pulping, cooking and adding cooking oil. Alternatively they may be chopped and boiled, fried or steamed, and cooked in soups and stews, as well as baby and pet foods

In India carrots are used in a variety of ways, as salads or as vegetables added to spicy rice or dal dishes. A popular variation in north India is the Gajar Ka Halwa carrot dessert, which has carrots grated and cooked in milk until the whole mixture is solid, after which nuts and butter are added. Carrot salads are usually made with grated carrots with a seasoning of mustard seeds and green chillies popped in hot oil. Carrots can also be cut in thin strips and added to rice, can form part of a dish of mixed roast vegetables or can be blended with tamarind to make chutney. Carrots are puréed and used as baby food, dehydrated to make chips, flakes, and powder, and thinly sliced and deep-fried, like potato chips. The sweetness of carrots allows the vegetable to be used in some fruit-like roles. Grated carrots are used in carrot cakes, as well as carrot puddings etc. Carrots can also be used alone or blended with fruits in jams and preserves.

2.5. Engineering Properties

The physical and engineering properties are important in many problems associated with the design of machines and the analysis of the behaviour of the product during post-harvest operations such as handling, threshing, cleaning, sorting and drying. The solutions to problems of these processes involve knowledge of the physical and engineering properties (Irtwange, 2000).

2.5.1. Physical Properties

Prior to the design and development of machine the physical properties *viz.*, sphericity, roundness, mass, geometric mean diameter, surface area, volume, porosity, true density, bulk density etc. are to be conducted.

Spoilage of agricultural produce at different stages such as harvest, transfer, transportation, and processing is caused by unexpected loads and stresses upon them. Moreover, in order to process agricultural produce, some loading needs to be done through cuts in or pressure on the product. Thus, to prevent mechanical harm and waste during the harvest processes and the stages after that and to optimize processing devices, it is necessary to measure and study physical properties of agricultural produce (Akbarnejad, Azadbakht, & Asghari, 2017; Vishwakarma, Shivhare, & Nanda, 2012).

2.5.1.1. *Size*

Size is the measure of physical dimensions of the object. Fruits and vegetables are irregular in shape and a complete specification of their form theoretically requires an infinite number of measurements. From practical point of view, measurements of several mutually perpendicular axes are to be taken. However, the measurements along major and minor axes were taken for describing the size of the bean (Mohsenin,1986).

According to Ahmad Jahanbakhshi *et al* (2018), to measure physical properties, 100 samples of carrot were selected randomly. Dimensions of the carrot (their length (*L*), width (*W*), and thickness (*T*)) were measured using a DC-515, Taiwan digital caliper with the precision of 0.01 mm. The mean length, width and thickness were found to be 154.55 mm, 28.61 mm and 27.60 mm.

Pandiselvam R *et al*. (2016) determined the physical properties of paddy (ADT-43) namely, size, shape, thousand paddies mass, aspect ratio, surface area, volume, bulk density, true density and porosity at moisture contents ranging from 11.86 to 23.61 percent d.b using standard techniques. At the moisture content of 11.86 percent (d.b), the average length, width and thickness of paddy (ADT-43) were 7.79, 2.38 and 1.77 mm, respectively.

Yuwana *et al*. (2015) characterized some engineering properties of coffee beans produced from wet process in respect to different colors of coffee cherries. The average values of length, width and thickness of coffee beans were 11.61 to 12.1 mm, 8.35 to 8.84 mm and 5.04 to 5.45 mm, respectively.

2.5.1.2. *Shape*

Shape characteristics are necessary for removing debris and other undesirable materials mixed with the dried fruits and also in the design of sorting and grading machinery (Loghavi *et al.,* 2010). The parameters to be measured for describing the shape of agricultural produce are roundness, equivalent diameter and sphericity.

Ahmad Jahanbakhshi *et al* (2018) reported that the sphericity, geometric mean diameter and aspect ratio of the carrot were 0.32%, 49.54 mm and 0.18 respectively.

Pandiselvam R., *et al*. (2016) reported that equivalent diameter, sphericity and aspect ratio of paddy increased from 3.22 to 3.39, 0.41 to 0.42 and 30.55 to 31.91 percent, respectively, with an increase in moisture content from 11.86 to 23.61 percent d.b.

2.5.1.3 *True Density, Bulk Density and Porosity*

Ahmad Jahanbakhshi *et al* (2018) reported that true density, bulk density and porosity of the carrots were 1.04 g/cm^3, 0.380 g/cm^3 and 63.46% respectively. Porosity and true density of paddy as reported by Pandiselvam R., *et al*. (2016) decreased from 46.82 to 38.27% and 1069 to 994 kg/m^3 respectively, with an increase in moisture content from 11.86 to 23.61%. Bulk density increased from 568 to 613 kg/m^3.

Yuwana *et al*. (2015) reported that the average values of porosity, bulk density and true density of coffee beans produced from wet process in respect to different colours of coffee cherries were 0.49 to 0.54, 740 to 788.9 kg/m^3 and 1551.3 to 1614.8 kg/m^3, respectively.

2.5.2. Optical Properties

Optical properties are those material properties resulting from physical phenomena occurring when any form of light interacts with the material under consideration. In the case of foods, the main optical property considered by consumers in evaluating quality is color, followed by gloss and translucency or turbidity among other properties.

2.5.2.1. *Colour*

Colour is an important quality attribute in the food and bioprocess industries, and it influences consumer's choice and preferences. Food colour is governed by the chemical, biochemical, microbial and physical changes which occur during growth, maturation, postharvest handling and processing. Colour measurement of food products has been used as an indirect measure of other quality attributes such as flavour and contents of pigments because it is simple, faster and correlates well with other physiological properties (Pankaj, 2013).

According to Magdalena Zielinska (2011), colour of carrots was estimated using L*, a*, b* parameters were calculated for measuring colour differences. The L*, a*, b* values for unblanched samples were: 55.35 ± 1.63, 28.90 ± 0.85, 40.05 ± 2.05, respectively. The measured L*, a*, b* parameters for blanched carrots were 66.91 ± 0.62, 36.64 ± 0.62, and 40.59 ± 0.40, respectively, where the L* value represents the lightness to darkness gradation, a* value represents the greenness to redness spectrum and the b* value represents the blueness to yellowness spectrum. The colour values (L*, a*, and b*) are the three dimensions which gives specific colour values of the products.

2.6. Performance Evaluation of Dryers

Vijayan Selvaraj *et al.* (2017) developed an indirect triple pass forced convection solar dryer and its performance was evaluated for drying of carrot slices. The drying experiments were carried out under the meteorological conditions of Coimbatore city in India during the year 2016. The experimental set-up consists of a blower, triple pass packed bed air collector (using sand) with wire mesh absorber plate, and a drying chamber. The air mass flow rate was optimized to 0.062 kg/s. The initial moisture content of the carrot slices was reduced from 87.5% (on wet basis) to the final moisture content of 10% (wet basis) in 6 h duration. The results showed that the pick-up efficiency of the dryer was varied in the range between 14 and 43% with an average air collector thermal efficiency of 44% during the experimentation.

Shawik Das *et al.* (2001) designed and developed a recirculatory cabinet dryer of capacity 5 kg/batch using a central air distribution system. The dryer was tested with blanched potato chips. At a constant air flow rate of 1.5 m^3/min and 65°C temperature, it took about 3 h time to reduce the moisture content from 856.94% (dry basis) to 9.98% (dry basis). The heat utilization factor (HUF) and thermal heat efficiency (THE) of the developed dryer was found to be 18.94% and 22.16%, respectively.

ICAR-CIFT has designed and developed an infrared dryer for efficient drying of fish and fishery products. A 5 kg capacity prototype of the infrared dryer was designed using marine plywood, infrared lamps, heating element and stainless steel trays. Energy requirement for drying was distributed by eight infrared lamps of 150 W each. Dryer was operated at no load and load conditions. Temperature attained in the dryer under no load condition was 60±0.5ºC within three hours of operation. Drying experiments conducted for fruits and vegetables also showed promising results. Performance evaluation of the dryer was conducted using different fish species like, threadfin bream, sardine, shrimps etc. Moisture content of shrimp was reduced from 77 (% w.b) to 10 – 12 (% w.b) in 5 h of drying at drying temperature of 60ºC, air velocity of 1.5 ms^{-1} and relative humidity of 60% (Manoj P Samuel *et al.*, 2018).

Theresa U. Nwakonobi *et al.* (2019) designed, constructed and evaluated the performance of a freeze dryer. Digital thermometer, vacuum gauge and stop-watch were used to determine the freezing temperature, freeze drying vacuum pressure and freeze drying time. Tomato, pepper and okra were tested on the freeze dryer and were freeze dried at a temperature of -2℃, -1.5℃ and -1.4℃ and vacuum pressure of -29 in Hg, -24 in Hg and -22 in Hg**,** the freeze drying time was 20 hours, 10 hours and 10 hours respectively. The freeze dried products were able to regain their freshness when reconstituted with water.

Oluwaeleye I O *et al.* (2013) developed and performed experimental evaluation of a batch hot air fluidized bed dryer for cassava particles. The test rig of fluidized bed dryer consists of a vertical column 400mm diameter with a physical height of 2960mm, a regulated centrifugal blower powered by a 1.5 Hp electric motor, and an air heater with a thermostat for selection of drying temperature of the fluidizing medium. A bed of 1.555kg cassava particles were fluidized at three different air flow rates: 043 kg/s, 0.05 kg/s and 0.056 kg/s in succession. The drying temperatures considered are at an interval of 20ºC. The minimum drying temperature is 60°C and the maximum temperature of160°C. The resident drying time for cassava particles in the dryer was found to decrease with increase in drying temperature. The heat source for drying came solely from the heated fluidizing air. It was also observed that the drying rate decreases with increase in air flow rate while it increases with drying temperature.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

The various engineering properties required to develop an infrared dryer are discussed in this chapter. Also the methodology of fabrication and evaluation procedures for infrared dryer and the optimization of process parameters are also mentioned in this chapter.

3.1. Raw Materials

Fresh carrots were procured from the local market. Materials for the construction of equipment were purchased from Coimbatore and Thrissur. Good quality carrots were used for the study. Carrots having rots and diseases were rejected. Fresh carrots were collected in polythene bags and transported with care to the laboratory. In the laboratory, carrots were stored at the refrigerated condition till the conduct of the experiment.

3.2. Sample Preparation

The carrots were washed using potable water followed by removing their greenly crowns and adhering root hairs. The carrots were sliced with 2.5 mm thickness using a vegetable cutting machine.

3.3. Determination of Engineering Properties of Carrot Slices

Prior to the development of the infrared dryer, the physical, optical and frictional properties of carrot slices were studied. Engineering properties such as size, bulk density, true density, colour and moisture content were determined by standard procedures as explained in the following section. Thermal properties of carrot were also found out.

3.3.1. Physical Properties

The important physical properties of carrot slices, such as moisture content, size, bulk density, true density and porosity were determined as per methods explained in the following sections.

3.3.1.1. Moisture Content

Moisture content of carrot was determined as per AOAC (2005) method by placing 5g of carrots samples in a hot air oven at 70ºC for 12 hours. The moisture content is expressed as percentage wet basis (w.b). The experiments were replicated three times and the average value was reported.

$$\text{Moisture content (\% w.b)} = \frac{Wi - Wd}{Wi} \times 100 \ldots. (3.1)$$

Where,

W_i- initial weight of the carrot, g

W_d- dry weight of the carrot, g

3.3.1.2. Determination of Size

Size refers to the characteristic of an object which determines the space requirement and is expressed in terms of length, width and thickness. The carrot slices were selected at random for the determination of the size. A digital vernier calliper was used to measure the diameter and thickness with a least count of 0.01cm.

3.3.1.3.Determination of True and Bulk Density

Carrots were put into a container with known mass and volume (250 ml) at a constant rate. Bulk density was calculated from the ratio of mass of carrots to the volume containing mass (Davies *et al*., 2014).

$$\rho_b = M_b / V_b \ldots. (3.2)$$

Where,

ρ_b- Bulk density, kg/m^3

M_b- Mass of the carrot, kg

V_b- Volume of the carrot, m^3

Known weight of carrots was transferred into a measuring cylinder. Slowly add toluene into the measuring to fill the voids. Measure the amount of toluene added. True density of carrot was determined using the following equation.

$$\rho_t = W / TV \ldots. (3.3)$$

Where,

ρ_t- True density, kg/m^3

W- Weight of carrot, kg

TV- True volume of carrot, m^3 = Bulk volume – Volume of toluene

3.3.1.4. Determination of Porosity

Porosity of the carrot was computed from the bulk and true density using a formula as explained by Mohsenin (1986). The reported values are means of 10 replications.

$$\text{Porosity} = \frac{(\text{True Density} - \text{Bulk Density}) \times 100}{\text{True Density}} \quad \text{.... (3.4)}$$

3.3.2. Frictional Properties

Coefficient of friction on stainless steel, mild steel and aluminium was determined using the method discussed below:

3.3.2.1 Determination of Coefficient of Friction

Coefficient of friction of carrot on different surfaces such as stainless steel, mild steel and aluminium was determined using the following method. A known weight of sliced carrot was filled in a PVC cylinder which is placed on a plane surface made of stainless steel. This is the total normal force (N) acting on the surface. A loop and pulley arrangement is provided to add weight at the other end of the sliding surface. After keeping the cylinder with carrots at one end of the sliding surface add weight until the cylinder containing material tends to start sliding from its initial position. This is the weight required to overcome the frictional force (F). The procedure is repeated for other surfaces such as aluminium and mild steel. Coefficient of friction was calculated using the following equation.

$$\mu = F/N \quad \text{.... (3.5)}$$

Where,

μ = Coefficient of friction

F = Frictional Force, kg

N = Normal Force, kg

3.3.3. Optical Properties

In the case of foods, the main optical property considered by consumers in evaluating quality is colour. Colour was determined as per method explained in the following section.

3.3.3.1. Determination of Colour

The colour of the sliced carrot was determined using colorimeter (HunterLab Colour Flex EZ). The ColorFlex EZ spectrophotometer is a versatile colour measurement instrument that can be used on products of virtually any size, and in industries as diverse as paint, food, and textiles. The instrument uses a xenon flash lamp to illuminate the sample. It works on the principle of collecting the light and measures energy from the sample reflected across the entire visible spectrum. The meter uses filters and mathematical models which rely on "standard observer curves" that defines the amount of green, red and blue primary lights required to match a series of colour across the visible spectrum. It provides a reading in terms of 'L', 'a' and 'b', The 'L' coordinate measures the value or luminance of a colour and ranges from black at 0 to white at 100. The 'a' coordinate measures red when positive and green when negative and 'b' measures yellow when positive and blue when negative. All the three standard colour parameters 'L', 'a' and 'b' were observed for day light colour. The colour meter was standardized using black and white ceramic calibration tiles. Readings were observed from three replicates of each sample and the mean values of 'L', 'a' and 'b' were reported.

Plate 3.1. HunterLab Colour Flex EZ

3.3.4. Thermal Properties

The thermal properties like specific heat, thermal conductivity, thermal diffusivity etc are useful for the development of dryer. The properties were measured using the standard procedures mentioned below.

3.3.4.1 Specific Heat

The specific heat may be defined as the amount of heat in kilojoules that must added to removed from 1 kg of a substance to change its temperature by 1 K. Specific heat of a material can be determined using the following equation:

$$C = \left(\frac{m}{100}\right)C_w + \left(\frac{100-m}{100}\right)C_d \quad .... (3.6)$$

Where,

m = Moisture content of material in wet basis

C_w = Specific heat of water

C_d = Specific heat of bone dry material

3.3.4.2. *Thermal Conductivity*

The thermal conductivity may be defined as the rate of heat flow through unit thickness of material per unit area normal to the direction of heat flow and per unit time for unit temperature difference. Thermal conductivity of a material can be determined using the following equation:

$$Q = KA\Delta T \quad .... (3.7)$$

Where,

Q = Amount of heat flow, J/s

K= Thermal Conductivity, W/mK

A = Area, m^2

ΔT = Temperature difference in the direction of heat flow, K

3.3.4.3. *Thermal Diffusivity*

The thermal diffusivity may be calculated by dividing the thermal conductivity with the product of specific heat and mass density. Thermal diffusivity of a material can be determined using the following equation:

$$\mu = \frac{K}{\rho Cp} \quad .... (3.8)$$

Where,

K = Thermal Conductivity, kW/mK

ρ = Mass Density, kg/m^3

C_p = Specific Heat, kJ/kgK

3.4. Development of Infrared Dryer

An infrared dryer was fabricated in the workshop of Kelappaji College of Agricultural Engineering and Technology, Tavanur. It consists of the following parts.

1. Drying chamber
2. Blower
3. Infrared heaters
4. Motor
5. Stainless steel trays
6. Control panel

3.4.1. Drying Chamber

It is one of the main components of the machine. The dimension of the chamber was optimized based on bulk density of carrot. The drying chamber is rectangular in shape of 0.647 m width, 0.65 m length and 0.625 m height. It is made up of marine plywood. Hot air is blown from the bottom of the chamber through an opening of 0.505 m width and 0.51 m length. Interior surfaces of the drying chamber are coated with glass wool and food grade stainless steel.

Plate 3.2. Drying Chamber

3.4.2. Blower

Blower is used to blow fresh air into the drying chamber. A three phase 0.5 HP centrifugal blower (leaf type) is attached to the drying chamber. The blower pumps air into the drying chamber at a velocity of 1 m/s. The function of blower is to provide uniform air circulation and also it collects moisture from the food material and dissipates it through the exhaust port.

Plate 3.3. Blower

3.4.3. Infrared Heaters

Two ceramic infrared heaters of 500 W and 240 V each are used to produce far infrared radiations (FIR) throughout the heating chamber. These radiations facilitate drying of the product. The infrared heaters have a Nichrome wire directly casted into ceramic and they produce high temperature (upto 650ºC). The infrared heaters have a glazed surface to prevent oxidation and corrosion and the concave surface focuses the energy more to a desired spot. Low thermic mass, optimal size, high efficiency, durability and shape flexibility are the benefits of infrared heaters over infrared bulbs.

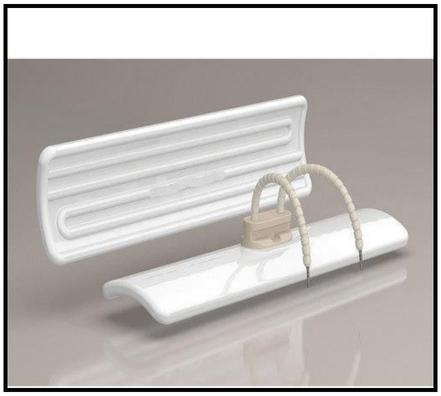

Plate 3.4. Infrared Heaters

3.4.4. Motor

A 1 HP 3-phase variable speed AC motor was employed to rotate infrared heating source. It is mounted to the shaft above the drying chamber to facilitate rotation of infrared heaters. The infrared heaters are rotated at a speed of 45 rpm.

Plate 3.5. Motor

3.4.5. Stainless Steel Trays

2 stainless steel horizontal trays of dimension 0.635 m x 0.61 m having 5 mm diameter perforations were used to load the samples.

Plate 3.6. Stainless Steel Trays

3.4.6. Control Panel

Control panel consists of the following components:

1. Power key
2. Indicators
3. Volt meter
4. Ammeter
5. Switches
6. Variable frequency drive
7. Regulator
8. Temperature controller
9. Emergency switch

3.4.7. Frame Assembly

The frame supports the entire machine component to perform. It was fabricated using GI square section. The units *viz.*, drying chamber, blower, infrared heaters, motor, control panel etc. were mounted on the frame.

Plate 3.7. Infrared Dryer

3.5. Experimental Design

The independent and dependent variables as well as other factors required for the design of the dryer considered in the study are given below.

3.5.1. Independent Variables

- Drying temperature (50ºC, 60ºC, 70ºC)

3.5.2. Dependent Variables

- pH
- Colour
- Vitamin A and β-carotene
- Protein
- Rehydration ratio

3.5.3. Operation of Infrared Dryer

Plate 3.7 shows the front view of developed infrared dryer. Carrots slices of mean diameter 23.76 mm and mean thickness 2.5 mm were fed into the infrared dryer manually. Power supply to the infrared heaters was switched on and the temperature was set accordingly. Fresh air was pumped into the chamber by the blower and the air velocity was set at 1 m/s. The infrared radiations emitted heats up the air inside the chamber to the required temperature. The heated air circulated throughout the drying chamber where the carrots were placed on a stainless steel tray.

Drying of carrots took place due to heat and mass transfer. The slow rotation of the infrared heaters helped in the proper and uniform drying of carrots. The dried carrots were then removed from the dryer and stored under suitable conditions.

Infrared drying involves a heat transfer by radiation between a hot element and a material at lower temperature that needs to be dried**.** The peak wavelength of the radiation is dependent of the temperature of the heated element. The heat energy is directly transferred from the infrared source to the product to be heated without the need of an intermediate such as air or water. All materials will absorb, reflect and allow a fraction of the infrared spectrum to pass through. Infrared drying has gained popularity as an alternative drying method for agricultural products. When infrared radiation is used to warm up or dry moist materials, it penetrates into them and the energy of radiation converts into heat. The use of infrared drying has several advantages in comparison with traditional convective drying methods. The advantages are summarized as follows: heat efficiency, high diffusion coefficient, low drying time and the equipment may be compact (Nowak and Lewicki 2004; Wu *et al*. 2014). This drying method is particularly suitable for thin layers of material with large surface exposed to radiation. Infrared drying has been investigated as a potential method for obtaining high quality dried foodstuffs, including fruits, vegetables and grains

3.5.4. Drying of Carrot in Infrared Dryer

30 g of sliced carrot having 2.5 mm thickness were placed in a tray and kept in the infrared dryer at three different temperatures *viz.,* 50ºC, 60ºC and 70ºC at constant air velocity of 1 m/s. Sample placed in hot air oven at a temperature of 70ºC was treated as control sample.

3.5.5. Optimization of Drying Temperature

Raw carrots procured from a local market from Tavanur, Malappuram district, were used for the conduct of the experiment. Testing was done at dryer temperature of 50ºC, 60ºC and 70ºC at constant air velocity of 1 m/s. Readings were taken at every 20 minute interval and drying curve was plotted. Quality parameters of dried carrots using infrared dryer such as size, shape, pH, colour, beta-carotene content etc. were determined and compared with that of control sample. The process parameters were optimized based on the quality of dried carrots.

3.5.6. Determination of Physico-Chemical Properties of Dried Carrots

3.5.6.1. pH

Five gram samples of carrots were homogenized for 30 s in 100 ml of hot distilled water and vacuum filtered through Whatman filter paper No. 4. A 25 ml aliquot was pipette into a beaker and the pH measured using a pH meter (Systronics Digital pH meter MK VI).

3.5.6.2. Rehydration Ratio

The rehydration ratio was carried out by immersing dried carrot slices in boiling water, maintained at three temperatures i.e. 50°C, 60°C and 70°C. Approximately 5 g of sample was added to 200 ml of water, agitated and then allowed to rehydrate for 30 and 60 min time intervals and the contents were then filtered through filter paper.

Dried carrot slices were evaluated for rehydration ratio to find the reconstitution of dried sample using the following formula:

$$\text{Rehydration Ratio} = \frac{W2}{W1} \times 100 \quad .... (3.9)$$

Where,

W_2=Weight of rehydrated sample, g

W_1=Weight of the dehydrated sample, g

3.5.6.3. Beta carotene content and vitamin A (µg/100g)

Reagents: Acetone, anhydrous sodium sulphate, petroleum ether.

5 g of fresh sample was taken and crushed in 10-15 ml acetone, adding few crystals of anhydrous sodium sulphate, with the help of pestle and mortar. The supernatant was decanted into the beaker. The process was reported twice and transferred the combined supernatant to a separatory funnel, adding 10-15 ml petroleum ether and mix thoroughly. Two layers was separated and the lower layer was discarded and upper layer was collected in a 100 ml with petroleum ether and optical density was recorded using petroleum ether as blank.

$$\text{B-carotene } (\mu/g) = \frac{\text{O.D} \times 13.9 \times 104 \times 100}{\text{Wt of Sample} \times 560 \times 1000} \quad .... (3.10)$$

The vitamin A was estimated according to the method described by Suman and Kumari (2002).

$$\text{Vitamin A (I.U)} = \frac{\beta\text{−carotene }(\mu g)}{100} \quad .... (3.11)$$

3.5.6.4. Determination of Protein

Kjeldahl method was adopted to analyze the protein content in the dried carrots and procedures were followed as outlined in Official Methods of Analysis of AOAC International (1995). The nitrogen in protein or any other organic material is converted to ammonium sulphate by H_2SO_4 during digestion. On steam-distillation, it liberates ammonia which is collected in boric acid solution and titrated against standard acid. Since 1ml of 0.1 N acid is equivalent to 1.401mg N, calculation is made to arrive at the nitrogen content of the sample.

Accurately weighed l00 mg of the sample (containing 1-3mg nitrogen) was transferred to a 30 ml digestion flask and digested. To this sample, 1.9 ± 0.l g potassium sulphate and 80 ± l0 mg mercuric oxide was added along with 2 ml con. H_2SO_4 and digested. As sample size was larger than 20 mg dry weight, 0.l ml H_2SO_4 was added for each l0 mg dry material. It was digested till sample solution becomes colourless. The solution was cooled and diluted with a small quantity of distilled ammonia-free water and transferred to the distillation apparatus When the nitrogen content of the sample is high, the digest was made up to a known volume and an aliquot transferred to the distillation flask. The Kjeldahl flask was rinsed with successive small quantities of water. An l00 ml conical flask containing 5 ml of boric acid solution with a few drops of mixed indicator was placed at the tip of the condenser. Sodium hydroxide solution (10 ml) was added to the test solution in the apparatus. After distillation, ammonia was collected (at least 15-20 ml of distillate should be collected). Tip of the condenser was rinsed and the solution was titrated against the standard acid until the first appearance of violet colour as the end point. A blank was prepared with an equal volume of distilled water and subtracted the titration volume from that of sample titre volume.

$$\text{Nitrogen (\%)} = \frac{(\text{ml HCl - ml blank}) \text{ x normality x } 14.01}{\text{Weight (g)}} \quad .... (3.12)$$

3.5.6.5. Determination of Water Activity

Water activity is used to predict the stability of the product with respect to microbial growth, chemical and biological reaction rates and physical properties during storage. Aqua Lab series 3 water activity meter (M/s Aqua lab, USA) was used to determine the water activity of dehydrated carrot slices. Water activity is measured by equilibrating the liquid phase water in the sample with the vapour phase water in the headspace and measuring the relative humidity of the head space. The water activity of dried carrot samples was carried out using Aqua lab water activity meter (M/s. Aqua Lab, U.S.A; model: Series 3TE). The carrot samples were filled in the disposable cups of the water activity meter and the sample drawer knob is turned to OPEN position. The product was then placed in the sealed chamber and turned the knob to READ position. The water activity of the sample was recorded with respect to atmospheric temperature.

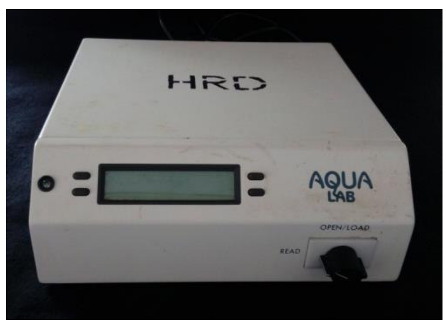

Plate 3.8. Water Activity Meter

3.5.6.6. Determination of Colour

The colour of carrots was determined using colorimeter (HunterLab Colour Flex EZ) as explained in section 3.3.3.1.

3.6. Performance Evaluation of Infrared Dryer

Performance of the infrared dryer was evaluated in terms of time required for drying, capacity, efficiency and energy requirement.

3.6.1. Determination of time required for drying

The carrots were dried at different drying temperatures till 10 percent moisture content (w.b) was attained and the time taken was recorded. Drying curve was plotted for carrots dried at three dryer temperatures (50ºC, 60ºC and 70ºC) with moisture content in percent (d.b) along the Y axis and time in minutes along X axis.

3.6.2. Determination of Capacity of Dryer

Size or capacity of a dryer is decided by the amount of carrot to be dried per unit time. Size of dryers are expressed in terms of holding capacity or amount of carrot to be dried per unit time or the amount of carrot fed to the dryer per unit time (Chakraverty, 1995).

3.6.3. Efficiency of Dryer

If the drying system is efficiently designed, the drying of products will be faster and uniform. Drying of products will take place within the desirable time and quality products will be obtained.

$$\text{Heat Utilization Factor, } h = \frac{T1-T2}{T1-Ta} \quad .... (3.13)$$

Where T_1 = Inlet (high) air temperature into the dryer

T_2 = Outlet air temperature from the dryer

T_a = Ambient air temperature.

.

3.7. Energy Requirement

Energy requirement is the power consumed per unit time. It was calculated as the product of power consumed and working time.

$$\text{Energy requirement (kWh)} = \text{Power} \times \text{Time} \quad .... (3.14)$$

3.8. Cost Economics

Cost of drying per year was calculated by considering the fixed and variable cost.

RESULTS AND DISCUSSION

CHAPTER IV
RESULTS AND DISCUSSION

This chapter deals with results obtained from various experiments conducted to determine the engineering properties of carrot and performance evaluation of the developed infrared dryer

4.1. Engineering Properties

The results of physical properties *viz.,* size, mass, porosity, density; optical properties like colour and frictional properties like coefficient of friction are presented and discussed in this section.

4.1.1 Physical Properties

Prior to the development of infrared dryer, selected physical properties of carrot slices *viz.,* moisture content, mean diameter, mean thickness, mass, bulk density, true density and porosity were investigated

The average values of various physical properties of carrot slices are presented in Table 4.1. The average moisture content of carrot was 81 percent (w.b). The average diameter and thickness of sliced carrots were found to be 23.76 and 2.5 mm, respectively. The average mass of an individual carrot slice was 1.4 g. The average true density and bulk density were 1.04 and 0.38 g/cm3, respectively. The average value of porosity was 63.46 percent.

Table 4.1. Physical Properties of Carrot

Sl No	Physical Property	Value
1	Moisture Content, % w.b	81
2	Mean Thickness, mm	2.5
3	Mean Diameter, mm	23.76
4	Mass , g	1.4
5	Bulk Density, g/cm3	3.86
6	True Density, g/cm3	10.4
7	Porosity, %	62.9

4.1.2. Optical and Frictional Properties

The optical property of raw carrots *viz.*, colour and frictional property *viz.*, coefficient of friction on three different surfaces were determined. The various optical and frictional properties of raw carrots are illustrated in Table 4.2. The colour of raw carrots was expressed in terms of L*, a* and b* values. The three coordinates represent the lightness of the colour (L* = 0 yields black and L* = 100 indicates white), its position between red/magenta and green (a*, negative values indicate green while positive values indicate magenta) and its position between yellow and blue (b*, negative values indicate blue and positive values indicate yellow). Coefficient of friction of raw carrot on three surfaces *viz.*, stainless steel, aluminium and mild steel was determined. A known weight (100 g) of carrot slices was placed in the PVC cylinder to determine the coefficient of friction.

Table 4.2. Optical and Frictional Properties of Carrot

Sl No	Property	Value
1	Colour	
	L*	46.89
	a*	31.17
	b*	43.15
2	Coefficient of Friction	
	Stainless Steel	0.6
	Mild Steel	0.7
	Aluminium	0.65

The average L*, a* and b* values of carrot slices were 46.89, 31.17 and 43.15, respectively. The coefficient of friction of carrots on stainless steel, mild steel and aluminium surfaces was 0.60, 0.70 and 0.65, respectively. This information is useful in estimating the power losses due to friction so that provision can be made for such in computing the power requirement of the machine, and in choosing the appropriate materials for fabrication (Maduako and Hamman, 2004).

4.2. Thermal Properties

The thermal properties of carrots were determined using the standard procedures. The various thermal properties of carrot are illustrated in Table 4.3. Thermal properties, *viz.,* specific heat, thermal conductivity and thermal diffusivity of carrots were found to be 1.85 kJ/kg K, 0.625 W/mK and 2.5 x 10^{-7} m^2/s. B R Becker *et al.* (2003) experimentally determined the value of specific heat of carrots as 1.88 kJ/kg K. Brettany Rupert *et al.* (2011) experimentally determined the value of thermal conductivity of carrots as 0.626 W/mK. L P Manalu *et al.* (1998) experimentally determined the value of thermal diffusivity of carrots as 2.51 x 10^{-7} m^2 /s.

Table 4.3. Thermal Properties of Carrot

Sl No	Thermal Property	Value
1	Specific Heat	1.85 kJ/kg K
2	Thermal Conductivity	0.625 W/mK
3	Thermal Diffusivity	2.5 x 10^{-7} m^2/s

4.3. Optimization of Drying Temperature

Trials were conducted to dry carrots at various temperatures *viz.*, 50ºC, 60ºC and 70ºC. The drying temperature was optimized based on the physico-chemical qualities of dried carrots.

4.3.1. Effect of Drying Temperature on pH

The effect of different drying temperatures *viz.*, 50ºC, 60ºC and 70ºC on pH of dried carrots is shown in Fig. 4.1. The pH of dried carrot increases with decreasing dryer temperature. The lowest pH of 5.15 was found in control sample. Among the samples dried using infrared dryer, the least value of pH was obtained for carrot dried at 70ºC and the highest value was obtained at 50°C. The pH values of carrot dried at 50ºC, 60ºC, 70ºC and control sample was 5.24, 5.20, 5.18 and 5.15, respectively. Shankaralingam (2004) reported that pH of carrots dried at 55ºC in a tray dryer was 5.20. Bonaparte (1998) reported that factors which inhibit enzyme activity, such as high temperature and reduced moisture, contribute to acid retention.

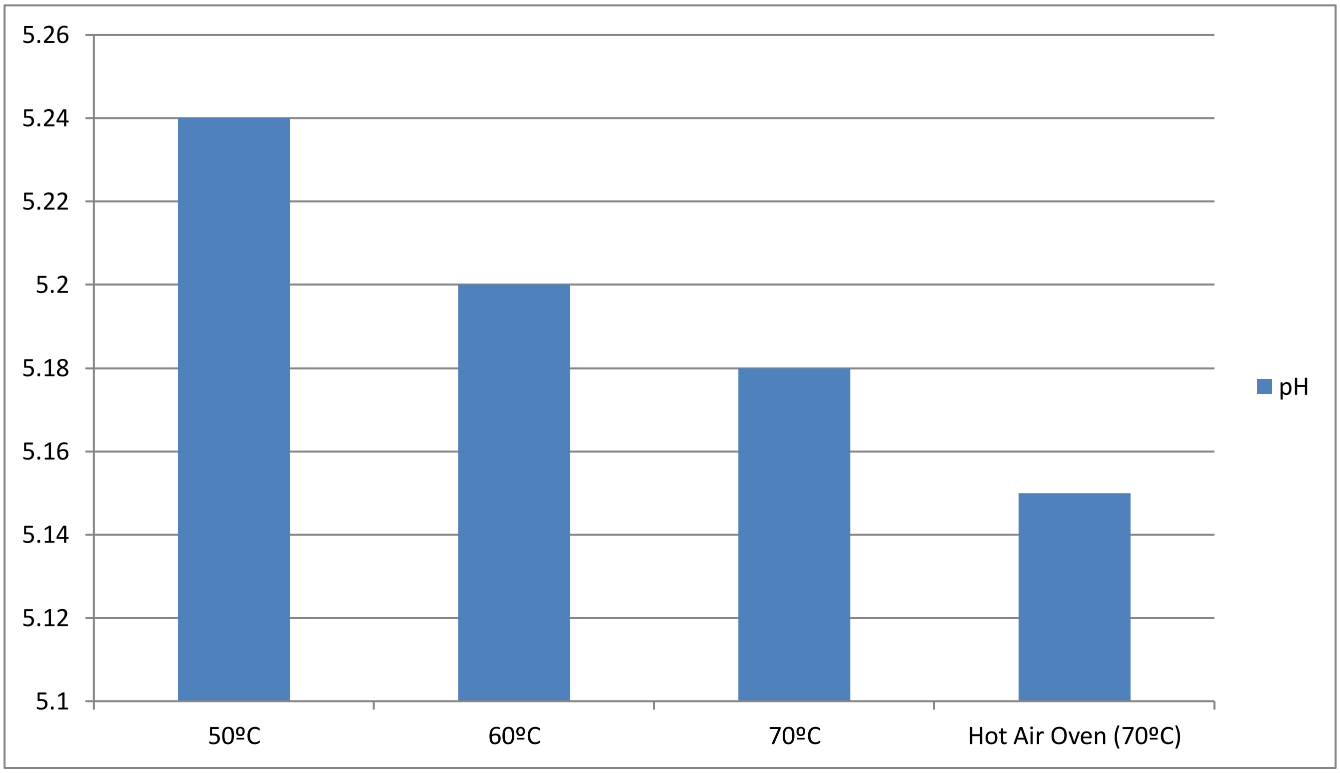

Fig. 4.1. Effect of Drying Temperature on pH

4.3.2. Effect of Drying Temperature on Rehydration Ratio

The effect of different drying temperatures *viz.*, 50ºC, 60ºC and 70ºC on rehydration ratio of dried carrots is presented in Fig. 4.2. The rehydration ratios of carrots dried at 50ºC, 60ºC and 70ºC in the infrared dryer after 30 minutes were found to be 3.62, 3.34 and 3.01 respectively, while the rehydration ratio of the carrots dried in the hot air oven at 70ºC was found to be 3.17. Similarly, rehydration ratios of carrots dried at 50ºC, 60ºC and 70ºC in the infrared dryer and control sample after 60 minutes were found to be 3.66, 3.38, 3.05 and 3.21, respectively. Naimish Gupta (2017) reported that the rehydration ratios of 5 g of dehydrated carrots at 50ºC, 60ºC, 70ºC and 80 ºC after 30 minutes were found to be 6.23, 6.29, 6.35 and 6.49, respectively, and the rehydration ratios after 60 minutes 6.27, 6.33, 6.39 and 6.46, respectively. The increase in the rehydration ratio was due to the absorption of water by the dried carrot slices. Rehydration ratio decreases with increase in dryer temperature. The least value of rehydration ratio was seen less for carrots dried at 70ºC whereas the carrots dried at 50ºC shown good rehydration properties.

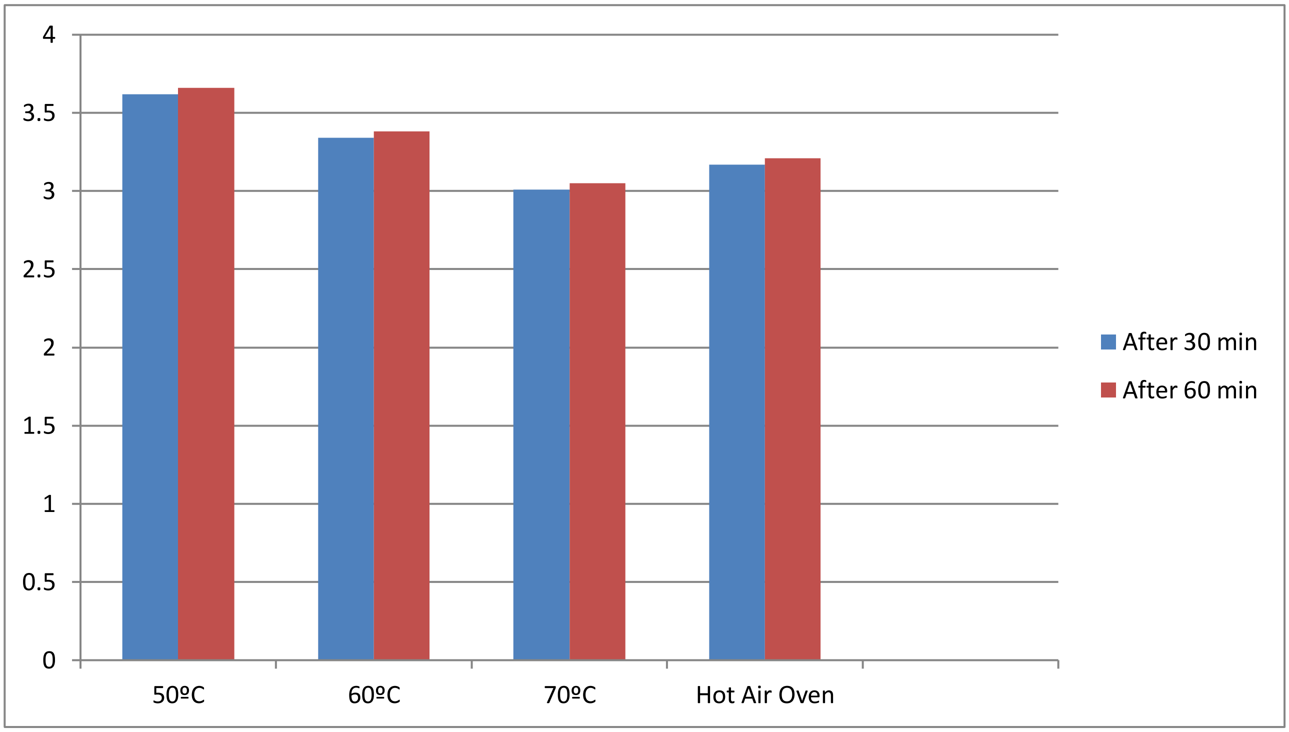

Fig. 4.2. Effect of Drying Temperature on Rehydration Ratio

4.3.4. Effect of Drying Temperature on β-carotene and Vitamin A content

The β-carotene and vitamin A content of fresh carrots are 75075.2 and 750.752 µg/100 g respectively. The effect of different drying temperatures *viz.*, 50ºC, 60ºC and 70ºC on β-carotene and vitamin A content of dried carrots are shown in Fig. 4.3 and Fig.4.4, respectively. The β-carotene content of carrots dried in the infrared dryer at 50ºC, 60ºC and 70ºC were 70225.6, 70070.8 and 69335.1 µg/100 g respectively, whereas the β-carotene content of carrots dried in the hot air oven at 70ºC was 45061.7 µg/100 g. The vitamin A content of carrots dried in the infrared dryer at 50ºC, 60ºC and 70ºC were 702.256, 700.708 and 693.351 µg/100 g respectively, whereas the vitamin A content of carrots dried in the hot air oven at 70ºC was

450.617 µg/100 g. It was found that both β-carotene and vitamin A content of dried carrots decreased with increase in temperature.

According to Shukla R N *et al.* (2017), carotenoids are the pigments which are sensitive to heat. During drying, thermal degradation occurs there by reducing the carotenoids and vitamin A content. Magdalena Zielinska *et al.* (2012) reported that drying significantly influenced the total carotenoids and β-carotene content. The higher the drying air temperature, the lower total carotenoids and β-carotene content was observed. The highest total carotenoids (158.70 ± 0.41 mg/100g d.b.) and β-carotene (96.60 ± 0.21 mg/100 g d.b.) content was noted for carrots dried at temperature of 60^{o}C. The lowest total carotenoids (122.68 ± 0.63 mg/100g d.b.) and β-carotene (66.85 ± 0.47 mg/100g d.b.) content were noted for carrots dried at 90^{o}C, which corresponded with the largest decrease in redness and yellowness. It might be due to the reaction of the product of carotenoid degradation, namely carbonylic compounds, with other food components (i.e., amine) and including them into the chain of Maillard reaction, which accelerate non-enzymatic browning. The degradation in lightness of carrots dried at 90^{o}C corresponded with degradation of thermo-labile components (carotenoids) under the influence of rigorous operating conditions.

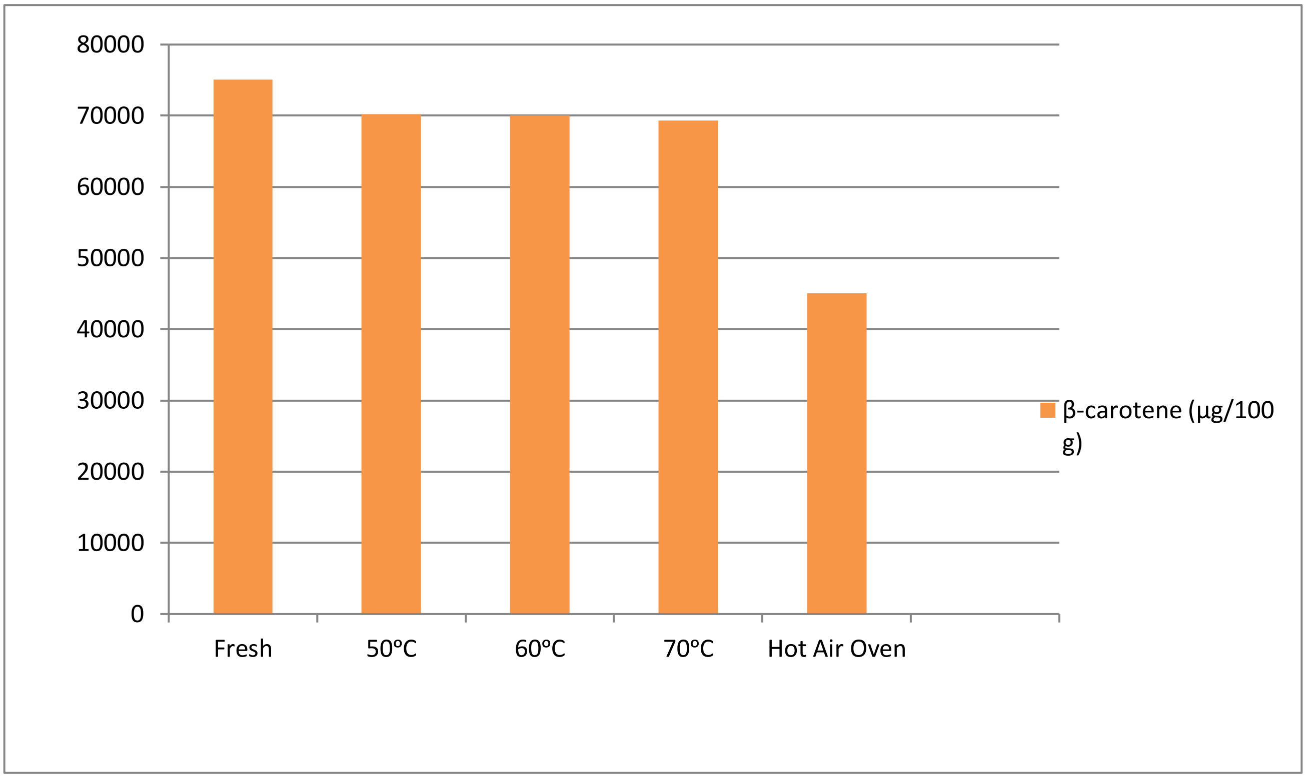

Fig. 4.3. Effect of Drying Temperature on β-carotene

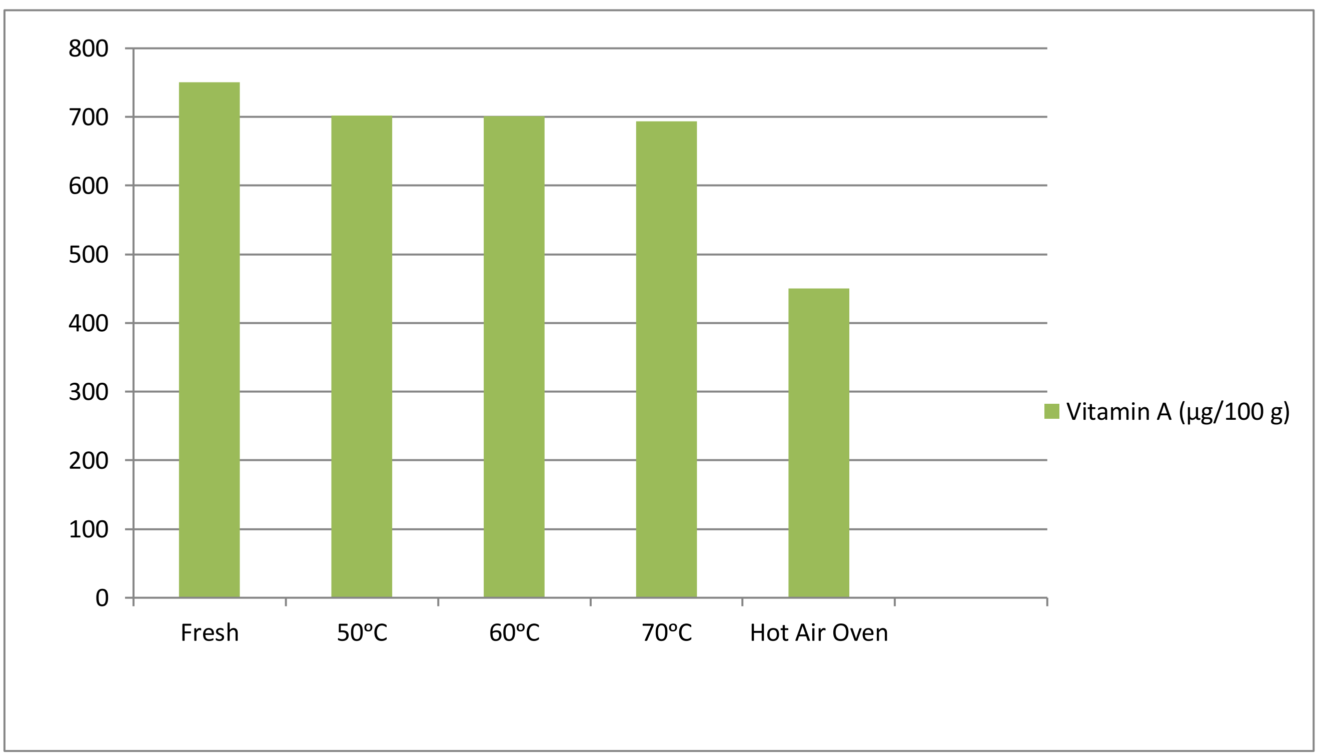

Fig. 4.4. Effect of Drying Temperature on Vitamin A content

4.3.5. Effect of Drying Temperature on Protein Content

The protein content in percentage of known weight of fresh carrots is 6.48%. The effect of different drying temperatures *viz.*, 50ºC, 60ºC and 70ºC on protein content of dried carrots are illustrated in Fig. 4.5. Protein content of carrots dried in the infrared dryer at 50ºC, 60ºC and 70ºC were 6.27, 5.81 and 5.35% respectively, whereas protein content of carrots dried in the hot air oven at 70ºC was 5.01%. It was observed that as temperature decreases, the protein retention increases.

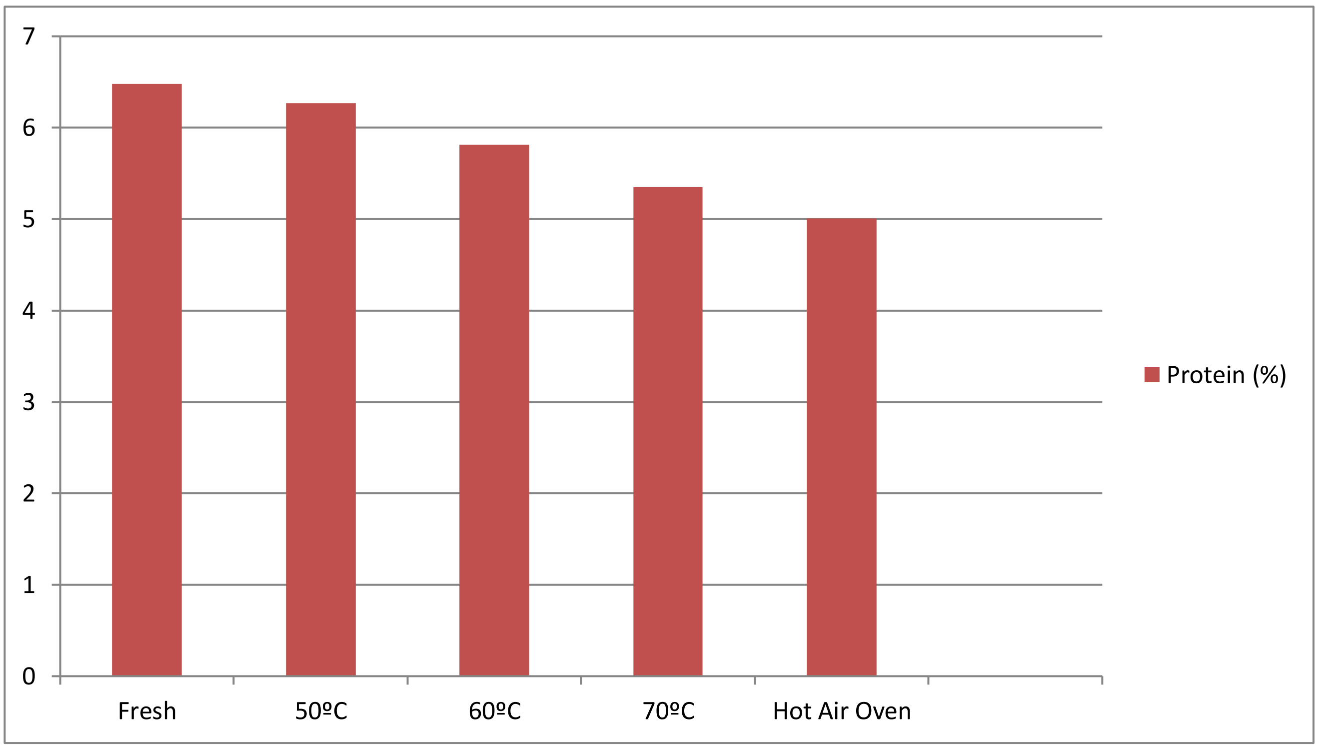

Fig. 4.5. Effect of Drying Temperature on Protein Content

4.3.6. Effect of Drying Temperature on Colour

The colour of dried carrots was expressed in L*, a* and b* values. The L*, a* and b* values of carrots are given in Table 4.4. It was observed that as temperature increases, colour retention decreases.

Table 4.4. Colour Values of Fresh and Dried Carrot

Sl No	Sample	Lightness (L*)	Redness (a*)	Yellowness (b*)
1	Fresh	46.89	31.17	43.15
2	50ºC	46.68	30.89	43.01
3	60ºC	44.3	26	39.8
4	70ºC	43.9	23.56	36.53
5	Hot Air Oven Dried (70ºC)	37.27	23.93	32.54

Plate 4.1. Dried Carrot Slices by Infrared Dryer

Plate 4.2. Hot Air Oven Dried Carrots

4.4. Water Activity of Carrots

Water activity is defined as the ratio of vapour pressure of the solution (of solutes in water in most foods) to the vapour pressure of solvent (usually water). The water activity for pure water is 1.00.

Water activity of fresh carrot slices, carrot slices dried at 50°C, 60°C, 70°C in infrared dryer and hot air oven dried carrot slices were found as 0.997, 0.684, 0.683, 0.681 and 0.679, respectively. According to Goldman *et al.* (1983), reduction of water activity is reported to result in a longer shelf-life of carrots. V Lavelli *et al.* (2007) reported that the reduction of water activity results in the arrest of microbial activity and minimizes enzymatic activities.

4.5. Performance Evaluation of Dryer

Performance of equipment is the basic criteria to evaluate its ability. The performance of the developed infrared dryer was evaluated in terms of time required for drying, capacity, efficiency and energy requirement.

4.5.1. Time required for drying

Total time required for drying carrot samples in infrared dryer at temperature 50°C, 60°C, 70°C and control sample were 2.5 h, 1.6 h, 1.5 h and 3.5 h, respectively.

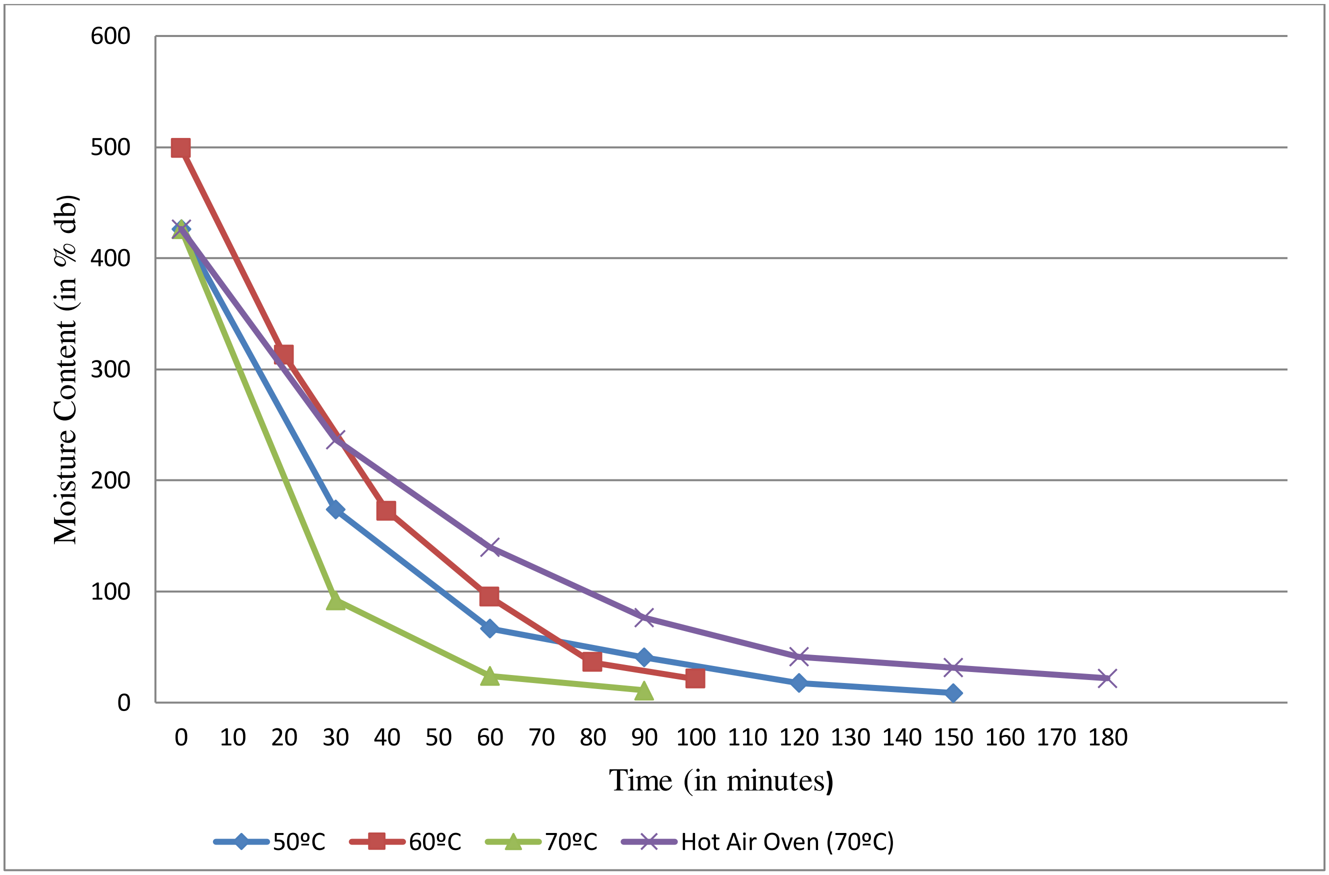

Fig. 4.6. Drying Curve of Carrot

Fig. 4.6 shows the drying curve of carrots dried using infrared dryer and hot air oven. The results showed that drying time reduced with increased in drying temperature. Ibrahim Doymaz (2015) prepared a drying curve for fruits and vegetables. He found that the moisture content decreased exponentially with elapsed duration of drying and decreased faster at higher temperatures. At higher temperature, the higher heat absorption resulted in higher product temperature, higher mass transfer driving force, faster drying rate and consequently lesser drying time. The moisture content of the product decreases continuously with diminishing drying time. This shows that diffusion is the most important physical mechanism governing moisture movement in the samples (Sharma *et al*. 2005; Kocabiyik and Tezer 2009; Nasiroglu and Kocabiyik 2009; Ponkham *et al*. 2012).

4.5.2. Capacity of infrared dryer

The capacity of the dryer depends on the dimensions of the dryer and the bulk density of carrots. The capacity of the infrared dryer was found to be 6.5 kg/batch.

Table 4.5. Performance Evaluation of Infrared Dryer

Particulars	**Drying Temperature (°C)**		
	50	**60**	**70**
Drying Time (h)	2.5	1.6	1.5
Capacity (kg)	6.5	6.5	6.5
Dryer Efficiency (%)	68.4	65.51	53.89
Energy Requirement (kWh)	5.3	3.4	3.2

4.5.3. Efficiency of Dryer

The efficiency of dryer primarily depends on the inlet air temperature, drying temperature and exhaust air temperature. Efficiency of the developed infrared dryer at drying temperatures 50ºC, 60ºC and 70ºC were found to be 68.4, 65.51 and 53.89 percent, respectively. A maximum efficiency of 68.4% was achieved when the infrared dryer was operated at a temperature of 50ºC at an air velocity of 1 m/s.

4.5.4. Energy Requirement

The energy requirement for the dryer was determined using energy meter. The average energy requirement for operating the dryer at different temperatures *viz.,* 50ºC, 60ºC and 70ºC were 5.3, 3.4 and 3.2 kWh, respectively. Minimum amount of energy was required when the dryer was operated at 70ºC. Among the carrot slices dried at 50ºC, 60ºC and 70ºC, carrot slices dried at 50ºC and 60ºC produced high quality product in terms of physico-chemical quality. By considering the efficiency and energy requirement of the dryer as well as the physico-chemical quality of dried carrot slices, carrot slices dried in the infrared dryer at 60ºC with an air velocity of 1 m/s was selected as the optimized parameter.

4.6. Cost Economics

The cost of the infrared dryer was found to be Rs 38,400. The cost of operation of infrared dryer was estimated as Rs 77.8/ hour. The detailed cost economics is given in Appendix-A.

SUMMARY AND CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSION

Various methods of drying have been developed for solids, and each method of drying has its own advantages and disadvantages. Sun drying being the most common method used to preserve agricultural products is extremely weather dependent, and has the problems of contamination with dust, soil, sand particles and insects. Hot air drying of food has low energy efficiency and needs long drying time during falling rate period. Because of the low thermal conductivity of food materials during this period, heat transfer of food during conventional heating is limited. The desire to eliminate this problem, to prevent significant quality loss, and to achieve fast and effective thermal processing, has resulted in the increased use of other techniques such as microwave and infrared drying. Infrared drying offers many advantages over conventional drying under similar drying conditions. When infrared radiation is used to heat or dry moist materials, the radiations impinge the exposed material, penetrate through it and the energy of radiation converts into heat. Infrared drying has been investigated as a potential method for obtaining high quality dried foodstuffs, including fruits, vegetables and grains. Hence, an attempt was made to develop an infrared dryer for fruits and vegetables.

Before the fabrication of the dryer, carrot was procured and its engineering properties were studied. Engineering properties of carrot *viz.*, moisture content, size, mass, bulk density, true density, porosity, optical properties *viz.*, colour, frictional properties *viz.*, coefficient of friction and thermal properties *viz.*, thermal conductivity, thermal diffusivity, specific heat and latent heat were determined by observing standard procedures. Infrared dryer consists of (a) drying chamber (b) blower (c) infrared heaters (d) motor (e) stainless steel trays and (f) control panel. The drying chamber is rectangular in shape having 0.647 m width, 0.65 m length and 0.625 m height. It is made up of marine plywood. Hot air is blown from the bottom of the chamber through an opening of 0.505 m width and 0.51 m length. Two ceramic infrared heaters of 500 W and 240 V are used to produce far infrared radiations (FIR) throughout the heating chamber. Two stainless steel horizontal trays of 5 mm diameter perforations were used to keep samples for drying.

The carrot samples were cut and fed to the trays of the infrared dryer manually. The infrared heaters placed inside the drying chamber heated up the air to the required temperature. Fresh air was pumped into the drying chamber using the blower. The heated air gets circulated inside the drying chamber where the samples are placed on the perforated stainless steel trays. The heat thus produced by the infrared radiations helps in reducing the moisture content of the sample by retaining the original colour and nutrients present in the sample.

30 g of carrot slices of initial moisture content 81% (w.b) were dried at 50 ºC, 60ºC and 70ºC at an air velocity of 1 m/s. Sample placed at 70ºC in a hot air oven was considered as control. Regular inspections were made and weights were noted at intervals of 20 minutes. Optimization of process parameters of dryer was done on the basis of physico-chemical properties of dried carrots *viz.*, pH, vitamin A and beta-carotene content, rehydration ratio, protein content and colour. Performance evaluation of the developed dryer was done in terms of capacity, energy requirement and efficiency of the dryer.

The results of above experiments are summarized as following:

- The moisture content of raw carrot was found to be 81% and final moisture content of carrot after drying was 10%.
- The mean diameter and mean thickness of raw carrot slices were 23.76 mm and 2.5 mm, respectively. The average mass, bulk density, true density and porosity were 1.4 g, 3.86 $g/cm^{3,}$ 10.4 g/cm^3 and 62.9% respectively.
- The colour of raw carrot and carrots dried using infrared dryer and hot air oven was expressed in terms of L*, a* and b* values. The average L*, a* and b* values of raw carrots were 46.89, 31.17 and 43.15, respectively. The L*, a* and b* values of carrots dried at 50ºC, 60ºC, 70ºC and hot air oven dried carrots was (46.68, 30.89, 43.01), (44.3, 26, 39.8), (43.9, 23.56, 36.53) and (37.27, 23.93, 32.54), respectively.

- Performance evaluation of the developed dryer was conducted in terms of its capacity, efficiency and energy requirement. Time required for infrared drying at 50ºC, 60ºC, 70ºC and hot air oven drying at 70ºC was 2.5 h, 1.6h, 1.5 h and 3.5 h, respectively. The capacity of the developed dryer was 6.5 kg. Efficiency of the infrared dryer at 50ºC, 60ºC and 70ºC was calculated as 68.4%, 65.51% and 53.89%, respectively. Energy requirement of the infrared dryer at 50ºC, 60ºC and 70ºC was found to be 5.3, 3.4 and 3.2 kWh, respectively.

Based on the quality evaluation of the dried carrot, samples dried using infrared dryer were found to be superior to hot air dried samples. Hot air oven method consumed more time to dry the carrots i.e. 3.5 hours. Among the infrared dried samples, carrot dried at 50ºC and 60°C produced high quality dried product in terms of physico-chemical qualities. By considering the dryer efficiency and energy requirement of dryer, carrot slices dried in infrared dryer at 60ºC with air flow rate 1 m/s was selected as the optimized parameter. The cost of the infrared dryer was found to be Rs 38400. The cost of operation of infrared dryer was estimated as Rs 77.8/ hour.

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CHAPTER VI

REFERENCES

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APPENDIX

APPENDIX-A

1. Cost Economics of Infrared Dryer

Capacity of Infrared Dryer = 6.5 kg/batch

Life Span of Infrared Heaters (n) = 5 years

Annual Usage = 120 days

Daily Usage = 6 hours

Interest Rate (i) = 10.5% per annum

Total cost of equipment (c) = Rs. 38400

A) Fixed Cost

i) Fixed Cost of Equipment = $\dfrac{i(i+1)^n}{(i+1)^n+1} \times C$

$$= \frac{0.105(0.105+1)^7}{(0.105+1)^7+1} \text{ x } 38400$$

= Rs. 2509.02/-

ii) Housing Charge = Rs. 100/month

Housing Charges per year = Rs. 1200/year

Total Fixed Cost per year = Rs. 2509.02 + 1200

= Rs. 3709.02/-

B) Variable Cost

i) Repair and Maintenance = 5% of initial cost

= Rs. 1920/year

ii) Labour Cost per day = Rs. 400

Total Labour Cost per year = Rs. 400 x 120

= Rs. 48000/year

C) Cost of Energy

Energy Requirement = 3.4 kWh

Electricity Charges = Rs. 5.85/kWh

Energy Consumption Charges = $\dfrac{\text{No:of days x Energy}}{\text{Day x Rate}}$

= 120 x 5.85 x 3.4

= Rs. 2386.8

Total Variable Cost = Rs. 1920 + 48000 + 2386.8

= Rs. 52306.8/-

Total Cost for Drying per year = Total Fixed Cost + Total Variable Cost

= Rs. 3709.2 + 52306.8

= Rs. 56015.82/year

= Rs. 466.79/day

= Rs. 77.8/hr

ABSTRACT

DEVELOPMENT AND PERFORMANCE EVALUATION OF INFRARED DRYER

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ABSTRACT

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IN

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ABSTRACT

Infrared drying has been investigated as a potential method for obtaining high quality dried foodstuffs, including fruits, vegetables and grains. Infrared drying offers many advantages over conventional drying under similar drying conditions. When infrared radiation is used to heat or dry moist materials, the radiation impinge the exposed material penetrate through it and the energy of radiation converts into the heat. This report outlines the development of an infrared dryer and the performance evaluation of dryer. The drying chamber is rectangular in shape of 0.647 m width, 0.65 m length and 0.625 m height. It is made up of marine plywood Hot air is blown from the bottom of the chamber through an opening of 0.505 m width and 0.51 m length. Two ceramic infrared heaters of 500 W and 240 V are used to produce far infrared radiations (FIR) throughout the heating chamber. 2 stainless steel horizontal trays of 5 mm diameter perforations were used to place the samples inside the dryer. 30 g carrots of initial moisture content 81% (w.b) were kept in the infrared dryer at 50ºC, 60ºC and 70ºC at an air velocity of 1 m/s. 150, 100 and 90 minutes was consumed to reduce the initial moisture content of 81% of carrot to a final moisture content of 10%. Therefore, when compared to the other conventional dryers, infrared dryer took less time to reduce the moisture content of the samples. Optimization of process parameters of dryer was done on the basis of physico-chemical properties of dried carrots (which was compared with fresh carrots) *viz*., pH, vitamin A and beta-carotene content, vitamin C retention, rehydration ratio, protein content and colour. The colour indicators, lightness/darkness (L*), redness/greenness (a*) and yellowness/blueness (b*) were analysed for the fresh and dried samples of carrot. L*, a* and b* values of both fresh samples and dried samples had only negligible differences indicating that there was no significant loss of colour during drying. Thus the colouring pigments present in the carrot were preserved during drying. The capacity of the dryer was found out to be 6.5 kg. Efficiency of the infrared dryer at 50ºC, 60ºC and 70ºC was calculated as 68.4%, 65.51% and 53.89%, respectively. The energy requirement for operating the dryer at 50ºC, 60ºC and 70ºC were found as 5.3, 3.4 and 3.2 kWh, respectively. Among infrared dried carrots, carrots dried at 50ºC and 60°C produced high quality dried carrots in terms of physico-chemical qualities. By considering the dryer efficiency and energy requirement of dryer, carrots dried in infrared dryer at 60ºC with air flow rate 1 m/s was selected as the optimized parameter. The cost of the infrared dryer was found to be Rs 38400. The cost of operation of infrared dryer was estimated as Rs 77.8/ hour.