DEVELOPMENT AND PERFORMANCE EVALUATION OF A BLANCHER CUM DRYER FOR JACKFRUIT

by

ANUPAMA B. M.
(2015-18-007)

THESIS

Submitted in partial fulfilment of the

requirement for the degree of

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(Agricultural Processing and Food Engineering)

Faculty of Agricultural Engineering & Technology

Kerala Agricultural University

DEPARTMENT OF FOOD AND AGRICULTURAL PROCESS ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679573, MALAPPURAM

KERALA, INDIA

2017

DECLARATION

I hereby declare that this thesis entitled **"Development and performance evaluation of a blancher cum dryer for jackfruit"** is a *bonafide* record of research work done by me during the course of research and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Tavanur: **ANUPAMA B. M.**

Date : **(2015-18-007)**

Dr. Sudheer K. P.
Professor, National Fellow (ICAR) & Project Coordinator
Centre of Excellence in Post-harvest Technology
Dept. of Agricultural Engineering
College of Horticulture
Kerala Agricultural University
Vellanikkara, Thrissur, Kerala.

CERTIFICATE

Certified that this thesis entitled **"Development and performance evaluation of a blancher cum dryer for jackfruit"** is a *bonafide* record of research work done independently by Ms. Anupama B.M. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

Tavanur **Dr. Sudheer K. P.**
Date: (Chairman, Advisory Board)

CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. Anupama B.M. (2015-18-007)** a candidate for the degree of Master of Technology in Agricultural Engineering majoring in Agricultural Processing and Food Engineering agree that the thesis entitled **"Development and performance evaluation of a blancher cum dryer for jackfruit"** may be submitted by **Ms. Anupama B.M. (2015-18-007)** in partial fulfillment of the requirement for the degree.

Dr. Sudheer K. P.
Professor, National Fellow (ICAR) & Project Coordinator
Centre of Excellence in Post-harvest Technology
Dept. of Agricultural Engineering, College of Horticulture
Kerala Agricultural University, Vellanikkara, Thrissur, Kerala.
(Chairman)

Dr. Santhi Mary Mathew
Professor and Head
Department of Food & Agricultural
Process Engineering,
KCAET, Tavanur.
(Member)

Dr. Rajesh G. K.
Assistant Professor
Department of Food & Agricultural
Process Engineering,
KCAET, Tavanur.
(Member)

Dr. Anu Varughese
Assistant Professor
Dept. of Irrigation & Drainage Engineering
KCAET, Tavanur.
(Member)

EXTERNAL EXAMINER
(Name and Address)

Dedicated to

My beloved parents

Smt.Vijayamma V.

Sri. Maddireddy S.

ACKNOWLEDGEMENT

It is a matter of pleasure to glance back and recall the path one traverses during the days of hard work and pre-perseverance. It has still great at this juncture to recall all the faces and spirit in the form of teachers, friends, near and dear ones. I would consider this work nothing more than incomplete without attending to the task of acknowledging the overwhelming help I received during this endeavour of mine.

My diction would be inadequate to express my deepest sense of gratitude and heartfelt thanks to Chairman of my Advisory Committee, ***Dr. Sudheer K. P.,*** *Professor and National Fellow (ICAR), Project co-ordinator (CE-PHT) Department of Agricultural Engineering, College of Horticulture, Vellanikkara, Thrissur. His level of guidance, constructive criticism, generous assistance at every stage of my research work is beyond measure, in fact it was his ideas, smooth dealing with the thing which motivated me to work under his guidance and any credit goes to him. It is my proud privilege to express my heartfelt indebtedness and deepest sense of gratitude for laying out the guidelines of research work. I have real admiration and regards for his full hearted support and untiring help.*

I take this opportunity to express sincere thanks to my advisory committee members ***Dr. Santhi Mary Mathew,*** *Professor, Dean & Head, Department of Food and Agricultural Process Engineering, K.C.A.E.T, Tavanur,* ***Dr. Rajesh G.K.,*** *Assistant Professor, Department of Food and Agricultural Process Engineering, K.C.A.E.T, Tavanur and* ***Dr. Anu Varughese,*** *Assistant Professor, Department of Irrigation and Drainage Engineering, KCAET, Tavanurfor their constant help, valuable suggestions during the investigation, sensible criticism in animating and*

ameliorating the manuscript and valuable counsel during the period of study and I owe them a lot for this small venture of mine.

My diction doesn't seem too rich enough to provide suitable words to articulate my sincere and heartfelt gratitude to ***Dr. Prince M.V.,*** *Professor,* ***Er. George Mathew,*** *Associate Professor,* ***Mrs. Sreeja R.,*** *Assistant Professor, Department of Food and Agricultural Process Engineering, K.C.A.E.T, Tavanur, for their valuable guidance, profound suggestions and constant encouragement and advice throughout the project work.*

I shall never forget the enormous and timely help rendered by Ph.D. scholars ***Er. Sankalpa K.B. and Er. Rana Salva*** *for their kind help and support during the course of study.*

I express my profound sense of gratitude to ***Er. Vimitha, T, RA*** *of CE-PHT* ***Mr. Sreenish kumar, N., Mr. Radhakrishnan, and Mrs. Geetha*** *Lab Assistants of Department of Food and Agricultural Process Engineering, and* ***Mr. Lenin.,*** *work shop staff of K.C.A.E.T, Tavanur for their for their help throughout my research work.*

Above all, my success would have remained an illusion without the ambitious encouragement, unquantifiable love, continued calm endurance, constant support and affection showered on me throughout the educational endeavour from my beloved parents ***Smt. Vijayamma, V. and Maddireddy S.*** *I have been highly fortunate and lucky to express my heartfelt respect to my dearest family members* ***late.Harish, Seenappa, Maddamma*** *and my relatives for their kind blessings and well wishes showed on me.*

I use this opportunity to sincerely thank my dearest classmates ***Cloudia, Srinivas, Saikrishna, Sreekutty, Pooja, Pravallika, Gayatri, Supritha, Ardra, Madhavi, Tejaswini, Naveen, Athul and Nithin*** *for their invaluable help during my study.*

I have no words to express my heartfelt thanks to my well wishers ***Dr. G.V. Srinivasreddy,*** *Asst. Prof. college of Agricultural Engineering, Raichur, and* ***Dr. A.B Narayanareddy*** *for their suggestion and support during my study.*

Selfless love is the dearest commodity on this planet and only a few in this world are kind enough to extent their helping hands, just for love and affection shown to me by my blossom friends, ***Chalapathi R, Anilkumar, Shashikumar, Santhosh N*** *and my seniors and juniors* ***Seema, Madhukumar, Chandankumar, Meghana, Niveditha, Venkatareddy*** *for their everlasting source of inspiration and love.*

I express my thanks to all the faculty ***members of Library****, KCAET, Tavanur for their ever willing help and co operation. I express my sincere thanks and gratitude to* ***Kelappaji College of Agricultural Engineering & Technology*** *for giving me an opportunity to undergo my P.G studies and* ***Kerala Agricultural University*** *for having proffered me a chance to study in this institution.*

One last word; since it is practically impossible to list all the names who have contributed to my work, I wish to thank all who directly or indirectly played pivotal role in successful completion of my post graduation and this manuscript

….. any omission in this small manuscript does not mean lack of gratitude.

Anupama B. M

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

SYMBOLS AND ABBREVIATIONS

%	:	Per cent
et al.	:	And others
Viz.,	:	Namely
et al.	:	that is
ie.,	:	that is
<	:	Less than
°C	:	Degree centigrade
±	:	Plus or minus sign
χ^2	:	Chi square
°B	:	Degree brix
ΔE	:	Total colour difference
°C	:	Degree centigrade
a*	:	Greenness or redness
a_w	:	Water activity
b*	:	Blueness or yellowness
cfu/g	:	Colony forming unit per ml
cm^3	:	Centimeter cube
d.b.	:	Dry basis
Df	:	Degree of freedom
G	:	Gram
g/100 g	:	Gram per 100 gram

h	:	Hour
H_2SO_4	:	Sulphuric acid
HCL	:	Hydrochloric acid
hp	:	Horse power
kCal	:	Kilo Calories
kg/h	:	Kilogram per hour
kJ/kg	:	Kilo joules
kPa	:	Kilo Pascal
kW	:	Kilowatt
kWh	:	Kilowatt hour
m/s	:	Meter per second
m^3/h	:	Meter cube per hour
mg	:	Milligram
ml	:	Milliliter
mm	:	Millimeter
N	:	Newton
N.sec	:	Newton second
No.	:	Number
pH	:	Potential of hydrogen
ppm	:	Parts per million
pps	:	Parts per second
R^2	:	Regression coefficient

rpm	:	Revolution per minute
w.b	:	Wet basis
μm	:	Micro meter
AC	:	Alternating current
ANOVA	:	Analysis of variance
AOAC	:	Association of Official Analytical Chemists
C.V.	:	Coefficient of variation
CB	:	Citric acid
FAO	:	Food and agricultural organisation
FCRD	:	Factorial Completely Randomised Design
Fig.	:	Figure
GDP	:	Gross domestic product
KCAET	:	Kelappaji College of Agricultural Engineering and Technology
KMS	:	Potassium metabisulphate
L*	:	Lightness or darkness
LDPE	:	Low density polyethylene
LED	:	Light emitting diode
MR	:	Moisture ratio
PFA	:	Prevention of Food Adulteration
RH	:	Relative humidity
RMSE	:	Root mean square error
ROS	:	Reactive oxygen species

SB	:	Steam blanching
SSE	:	Sum square error
Std. Dev	:	Standard deviation
TA	:	Texture analyser
TAA	:	Total antioxidant activity
TC	:	Total carotenoids
TCC	:	Total carotenoid content
TIG	:	Tungsten Inert Gas
TPC	:	Total plate count
TSS	:	Total soluble solids
UT	:	Untreated
WB	:	Water blanching

CHAPTER I

INTRODUCTION

India is the second largest producer of fruits and vegetables next to China. Horticulture contributes to about 30% of agriculture GDP, by using only 17% of the land area. Fruits and vegetables contribute to essential nutrients in daily human diet. Fruits and vegetables are rich in minerals, nutrients including vitamin C, vitamin K, thiamin, carotene, dietary fibre and antioxidant phyto-compounds required for maintaining health (Nirmala, 2010). Among all the fruits and vegetables, jackfruit is one of the most consumer's attractive fruit due to its edible, delicious, attractive bulbs and nutritious nature. Jackfruit in the tender and mature stage used as a starchy vegetable and in the ripen stage used as a raw eaten fruit. Jackfruits are tropical fruits rich in vitamin B, vitamin C, dietary fibre, protein, potassium, calcium, iron, proteins, high level of carbohydrates and many other nutrients (Jagtap *et al.*, 2010). The indigenous fruits which are locally available in a particular season play a vital role in the nutrition of rural mass. Nearly 40% of fruits and vegetables go waste due to their perishable nature, lack of appropriate post harvest equipments, postharvest infrastructure and faulty transportation, inadequate marketing set up, integrated supply chain and storage facilities during peak seasons of harvesting both in quality and quantity (Sadhu and Chattopadhyay, 2001; Global Village Fruit, 2013). Jackfruit is one among the various fruits, which are being wasted abundantly, with wastage of 75% annually due to lack of proper processing technologies. The raw jackfruit transportation and storage is not particularly economical because of its low yield of edible portion (around 35% of whole fruit) Saxena *et al.* (2012).

Jackfruit, (*Artocarpus heterophyllus L.*) belongs to family 'Moraceae' and is one of the most popular and widely grown, evergreen fruit trees in the country. It is large sized tree and bears the largest fruit among the edible fruits. Jackfruit originated in India and is now widely cultivated in South and South-East Asia. This is one of

nutritious fruits, indigenous to the rainforests of Western Ghats, Kerala, Karnataka, Assam, Bihar and hills of Himalayas in India (Reddy *et al*., 2004). According to 2014-15 statistics (NHB, 2015), area under jackfruit cultivation in India is 1,49,000 ha and its annual production is 20,37,000 T. Among the jackfruit producing states, Kerala contributes the highest share 41% of the overall production of jackfruit in the country (Anon., 2015).

Jackfruit has four stages of maturity: tender, slightly grown, unripe and ripe. In the first three stages, it is a very good vegetable and in the ripening stage it is a fruit (Swami *et al.*, 2012). On an average, jackfruit tree produces 20 to 250 fruits per year, sometimes upto 500 fruits in old trees. It produces heavier yield than any other tree species. Jackfruits are tropical fruits rich in dietary fibre, protein, potassium, vitamin B, vitamin C and many other nutrients (Jagtap *et al.*, 2010). Jackfruit has short shelf life of about three to ten days depending on the maturity, ambient temperature and relative humidity (RH) conditions (Haq, 2006). Though it is a seasonal crop, adoption of proper post harvest technology can ensure its availability throughout the year and enhance the shelf life. In addition jackfruit has good potential for value addition in the form of dried jack flakes, pickles, chips, jack leather, papad squash, jam, candy, halwa etc.

Preservation of fruits by processing has been the research pursuits of many developed and developing countries and has yielded a number of technologies. Despite the fact that its production is high, processing of jackfruit is very scanty. There has been a limited research to explain the possibilities of processing of jackfruit into durable and nutritious food products. Drying is one of the preservation methods to prolong the shelf life of jackfruit bulbs by removing water, thus reducing the size and weight up to 95% making it convenient for handling, storage and transportation processes (Taib *et al.,* 2013). Drying inhibits the growth of microorganism and enzymatic activities and avoids food damage and spoilage. The physical changes *viz.,*

shrinkage of cells, loss of rehydration ability, wettability, case hardening and chemical changes like changes in pH, TSS, vitamin C etc., may also occur during drying process.

Acceptability of dried foods is usually based on the retention of nutritive value and colour of the product during storage. Therefore, different pre-treatments are required to maintain the quality of dried foods. Pretreatments are usually carried out by dipping samples in certain chemical preservatives to reduce the drying time and colour losses, browning reaction, maintaining the firmness and improving the organoleptic quality of various produce along with extension in their shelf-life (Fellows, 2000; Martinez-Ferrer *et al.,* 2002).

Blanching is one of the thermal pre-treatment that is usually performed prior to drying, freezing, frying, and canning. The main purpose of blanching is to inactivate the quality-deteriorating enzymes, decreasing the microbial load and removing the toxic substances, enhancing the drying rates and product quality, minimizing non-enzymatic browning reactions and increasing extraction efficiency of bioactive compounds. Water and steam blanching are the two commercially adopted blanching processes. Steam blanching is a heat pre-treatment that inactivates the enzymes (peroxides and catalase) and reduces deterioration, such as undesirable colour, flavour or texture changes in the product (Severini *et al.,* 2005). Steam blanching requires less time than water blanching because the heat transfer coefficient of condensing steam is greater than that of hot water. In addition, leaching of water soluble nutrients were reduced compared to water blanching (John, 2004).

In traditional, jackfruit drying processes a protocol with separate blanching and drying units are practiced. These separate units/ machines will increase the cost of production and fabrication due to material cost, process time, energy, labours cost and plant space utility. Moreover manual handling of bulky equipments in industries is quite difficult for workers.

As a solution to eliminate all these problems, it is envisaged that there is a good scope for development of a two-in-one combo dryer *ie*., blancher cum dryer for jackfruit processing. Hence, present investigation was undertaken with following objectives:

1. To develop a blancher cum dryer suitable for drying jackfruit slices.
2. To evaluate the performance of developed blancher cum dryer unit.
3. To standardise the process parameters of the developed unit by assessing the quality parameters of dried jackfruit slices.

CHAPTER II

REVIEW OF LITERATURE

This chapter sets out to identify and critically analyse all the previously published literature with regard to the development of dryer and blancher, chemical composition of jackfruit, process parameters standardisation, drying experiments at different temperatures, drying rate, mathematical modeling, quality and sensory analysis of slices, shelf life studies and energy consumption.

2.1 NUTRITIONAL COMPOSITION OF JACKFRUIT

Bhatia *et al.* (1955) reviewed that the edible portion of jack fruit contained ash (6.49%), protein (10.51%), crude fibre (27.64%), reducing sugar (1.07%), total sugar (1.11%), starch (18.74%), carbohydrates other than sugars and starch (26.79 mg), Calcium (881.4 mg) and iron (15.62 mg).

Jackfruit slices contain high nutritional value; every 100 g of ripe fruit pulp contains 77% of moisture, 18.9 g carbohydrate, 1.9 g protein, 0.1 g fat, 1.1 g fibre, 0.8 g total mineral matter, 20 mg calcium, 30 mg phosphorus, 500 mg iron, 30 mg thiamin, and 84 Calories (Samaddar, 1985). Jackfruit is rich in vitamin B, vitamin C, potassium, calcium, iron, proteins and high level of carbohydrates, affordable and readily available supplement to our staple food.

Patil, (2012) reported that the fresh jackfruit bulb contained 75.08% moisture content, 0.16% titrable acidity, 1.36% reducing sugars, 1.20% non reducing sugars and 17.92% starch, 5.09°B TSS, 520.17 μg/100g beta-carotene and 5.27 pH.

Biworo *et al.* (2015) evaluated that jackfruit extract exhibited antioxidant and antidiabetic activities by decreasing the formation of reactive oxygen species (ROS).

They also reviewed that jackfruit exerted many biological activities, including anti-bacterial, anti-diabetic, anti-inflammatory, antioxidant and antihelmintic activities.

2.2 POST HARVEST UTILISATION

Fruit quality and shelf life is dependent on maturity at harvest. Though it is a highly nutritious commodity, the post harvest wastage is huge due to its perishable nature.

Jackfruits in mature stage used as a vegetable in preparation of curries and salads Narasimham (1990). Ripe fruits can be eaten as raw, cooked in creamy coconut milk as dessert, prepared into candied jackfruit or leather.

Roy and Joshi (1995) stated that pureed jackfruit could also be developed into juice, jam, jellies and base for cordials jackfruits were also used to make candies, fruit-roll, marmalades and ice cream.

According to Nakasone and Paul (1998) dried jackfruit pulp could also be used for further processing to produce jackfruit leather and jackfruit chips.

Jagdeesh *et al.* (2006) evaluated that some fruits of jackfruit trees which are grown in the desert areas may not be suitable for preparing chips this is because of variation in their biochemical composition. Under such conditions, adoption of proper post harvest technology was necessary to avoid post harvest losses and to make use of on seasonal production of jackfruit.

After harvesting fruit deteriorates rapidly upon ripening, it is desirable to develop value-added products from the matured and ripened bulbs. Jackfruit bulbs have been processed into various value-added products such as canned juice, fruit leather, fruit bar, minimally processed bulbs and hurdle technology preserved bulbs and also extend shelf-life of jackfruit bulbs (Saxena *et al.,* 2009). In addition to these value-added products, there is also a scope for dehydrated crisps from jackfruit bulbs.

Jackfruit bulbs are all over the world consumed as a dessert fruit or processed in to a variety of forms like finger chips, halvah, papad, ready-to-serve beverages, toffee, and milk-based srikhand, ice cream, and kulfi. Matured bulbs can be processed into bulb powder and further utilised for the preparation of traditional snacks such as pakoda, biscuits, and muffin Swami *et al.* (2012).

Matured unripe jackfruit bulb dried and powder is used in the fortification to enhance nutritional and sensory qualities of sweet biscuits Hosamani *et al.* (2016).

2.3 PRETREATMENT

Pretreatments before drying were done in order to minimise adverse changes occurring during drying and subsequent storage.

Effect of steam blanching on kiwifruit was assessed by Llano *et al.* (2003) for kiwifruit samples. Changes in colour, peroxidase and pectinmethylesterase activities were also determined. Blanching process was carried out for about 5 min and breakdown in cell membrane was observed and as increasing in the blanching time firmness was decreased. Even after standardising the blanching time for 1 min tissue was affected.

According to (FAO, 2004) the samples before drying, dipping in citric acid and 0.5% metabisulphite or lime prior along with steam blanching is sometimes used to prevent browning of light coloured food.

Pretreatments such as blanching along with 0.5% citric acid were given prior to drying process for amasya red apples by Doymaz (2010). It was concluded that drying times were affected by both drying temperature and pre-treatments. Shortest drying times were obtained when the samples were pretreated with citric acid solution. Blanched samples have higher rehydration ratios than other samples.

Prajapati (2011) carried out experiment on drying Indian gooseberry shreds. For the production of dehydrated aonla shreds two blanching methods (hot water and KMS at 0.1%) and two drying methods (solar and hot air oven drying) were carried out. The best quality retained product was obtained when sample treated with KMS blanching and solar drying with common salt at 3%.

The effects of different pre-treatments and air drying temperatures on colour characteristics, total carotenoid content (TCC) and total antioxidant activity (TAA) of gac fruit powder was assessed by Kha *et al.* (2011). Results reported that pre-soaking in solutions of ascorbic acid or bisulfate prior to air drying (40°C) was more effective in retaining the TCC and TAA. As increasing in the drying temperatures (50, 60, 70, and 80°C) loss of TCC and TAA was increased.

Alam *et al.* (2013) conducted an experiment on drying of carrot pomace and subjected to various blanching pretreatments *i.e.*, water blanching (WB), steam blanching (SB), citric acid (CB) and potassium metabisulphate (KMS) dipping after blanching (WB). A control sample untreated (UT) was kept for comparison. The blanched samples were further dried at various drying methods *viz.*, convective drying (55°C and 65°C), sun drying and solar drying. Results concluded that the samples convective dried at 65°C temperature exhibited a minimum drying time with higher retention of fibre, total carotenoids, beta-carotene content and colour parameters. Among all the blanching pretreatments, the citric acid pretreatment showed better efficiency in retaining the quality attributes. The carrot pomace samples which are pretreated with citric acid blanching followed by convective drying at 65°C was found to be the best drying combination for retaining the quality attributes.

Phungamngoen *et al.* (2013) carried out experiment on the resistance of *Salmonella* attached to cabbage leaves surfaces as well as some physical properties, in terms of colour and shrinkage. The cabbage were pretreated by soaking in 0.5% (v/v) acetic acid for 5 min, blanching in hot water for 4 min or blanching with saturated

steam for 2 min prior to hot air drying, vacuum drying (10 kPa) or low-pressure superheated steam drying (10 kPa) at 60ºC. Drying along with pretreatments completely inactivate the *Salmonella* attached on the cabbage surfaces. Dried blanched samples exhibited greener, darker colour and less volume shrinkage than the acetic acid pretreated and untreated samples.

Patil *et al.* (2014) optimised the dehydrated chips of jackfruit pre-treated with five treatments blanching, blanching and calcium chloride (0.5%), blanching and citric acid 0.5%, blanching and ascorbic acid 0.4% and controlled samples. These samples were stored for period of 0, 30 and 60 days and evaluated to study their impact on chemical composition of chips. Results indicated that samples pretreated with blanching and ascorbic acid were rich in moisture, TSS, acidity, reducing sugars, total sugars, non reducing sugars and beta-carotene, while starch and pH content of dehydrated chips were maximum in combination of blanching and calcium chloride (0.5%).

Effect of pretreatment on storage life and rehydration of dehydrated kakrol was investigated by Patro and Emmanuel (2014). Samples were pretreated with various combinations *i.e.,* 10% brine solution, 2000 ppm KMS, 1% turmeric powder with different blanching time and were dried in cabinet dryer at 60 and 80ºC. Results reported that cooking quality decreased with increase in storage period. After six months of storage samples which were treated with blanching for 30 s and 2000 ppm KMS recorded highest cooking quality, rehydration and overall acceptability.

Hossain *et al.* (2014) performed the blanching pretreatment with 0.5% KMS for 10 min for sliced jackfruit seeds. Results reported that treated samples were nutritionally better than control sample.

Blanching is one of the most essential pretreatment for extending the shelf life of fruits and vegetables. Praveena and Sudheer (2015) optimised the blanching treatment and time for tender jackfruit. Blanching time of three minutes and 0.3%

citric acid as a preservative was optimised for inactivation of peroxidase and catalase enzymes.

2.3.1 Blanching

Blanching is one of the most commonly used heat pre-treatment to inactivate the enzymes (catalase and peroxidase) responsible for quality deterioration of processed vegetables and it can be carried out under high temperature (Shivhare *et al.*, 2009). Blanching process for fruits and vegetables is generally carried out by heating them with steam or hot water. The vegetables soaked in boiling water for water blanching. In case of steam blanching, the vegetables are exposed to steam which is obtained on above the boiling water. Greater loss of nutrients usually obtained in water blanching, compared to steam blanching it takes less time. Steam blanching may prevent loss of nutritive compounds such as water-soluble vitamins.

Tunde-Akintunde *et al.* (2011) evaluated the effect of various blanching (steam, water, palm oil/water and groundnut oil/water) methods and drying temperatures (50, 60, 70, 80 and 90ºC), on bell pepper. Results reported that steam and water blanching as pretreatments increases the drying rates and improves the quality of dehydrated products. Blanching as a method of pretreatment generally increases water diffusion.

Heras-Ramirez *et al.* (2012) investigated the effects of blanching and drying treatments on stability, physical properties, antioxidant, and polyphenol properties of apple pomace. Blanched and unblanched samples of apple pomace were dried with a speed of 3 m/s in a cabinet dryer at 50, 60, 70, and 80°C. Results reported that compared to fresh unblanched apple pomace blanched samples caused a major retention in colour, total polyphenolic content, and total flavournoids. Higher antioxidants were attained in apple pomace when combination of both blanching and drying processes was carried out.

Pritty and Sudheer (2012) standardised the blanching time in hot water blanching for tender jackfruit of '*Varikka'* variety. Results explained that at one min of water blanching, enzyme inactivation occurred by maintaining good colour and texture.

2.3.1.1 Steam blanching

The stability and composition of total carotenoids in carrots at different blanching (steam, water and microwave) and drying (cabinet and fluidized bed drying) process were estimated by Sharma *et al*. (2000). Higher losses of total carotenoid were obtained in unblanched and fluidized bed dried samples compared to blanched and cabinet dried samples. Blanching treatments were influenced to occur the non-enzymatic browning reactions during storage. It was revealed that steam-blanching prior to drying of carrots minimizes the loss of carotenoids compared to microwave and water blanching.

Compared to water blanching, steam blanching requires less time due to the heat transfer coefficient of condensing steam is greater than that of hot water Jose *et al*. (2004). The high-temperature gradients are obtained between the surface and the center of the product, chances of over blanching are more near the surface than the centre.

Tunde-Akintunde and Ogunlakin (2013) estimated the temperature and pre-treatments effect on thin layer drying of pumpkin in a hot-air dryer. The drying times were decreased from 5 h to 4 h when the drying temperature increased from 40 to 80°C with constant air velocity of 1.5 m/s. Compared to untreated samples pretreated samples will dry faster. Pretreated steam blanching samples had shorter drying times (higher drying rates) when compared to water blanched, oil-water blanched and control samples. The entire drying process was mainly observed in falling rate period than constant rate period.

Experiment on effect of steam blanching and drying on retention of phenolic compounds of litchi pericarp at drying temperature of greater than 60ºC and drying at ambient temperatures for a long duration was carried out by Kessy *et al.* (2016). The combination of steam blanching and hot air oven drying treatments lead to a higher recovery of the phenolic compounds and enhanced the antioxidant capacity. Combination of steam blanching and hot air oven drying (60ºC) as a pre-treatment may be most favourable for better recovery of bioactive phenolic compounds from litchi pericarps.

2.4 DRYING CHARACTERISTICS OF JACKFRUIT

Dehydration is an important unit operation in chemical and food processing industries. The purpose of drying food products is allowed to store for longer period with minimised packaging requirements and reduced shipping weights and cost. In drying the water is usually removed as a vapour by air.

Okos *et al.* (1992) suggested that hot air drying was the most commonly used dehydration method for preservation of food on a global scale. The main attribute drying process was to decrease the water activity in the final product by decreasing its water content, inhibiting the growth of microorganism and decreasing spoilage reactions, to prolong the shelf-life of the product. Important advantage of dehydrated products is their cost of packing; storage and transportation are reduced due to the comparatively smaller volume and mass of the dried product.

Jackfruit has short shelf life, only about three to ten days depending on the maturity, ambient temperature and relative humidity (RH) conditions (Haq 2006). Dehydration is one of the preservative methods to prolong shelf life of jackfruit bulbs. During dehydration process, large portion of water content is removed from jackfruit bulbs. This inhibited the growth of microorganisms, enzymatic activities, avoided

food spoilage and damage by reducing the size and weight up to 95%, which made it convenient for handling, storage and transportation processes.

According to Kumar *et al.* (2011), the modes of heat transfer involved in convective drying of foods were heat and mass transfer. In convective drying, the flow of heat and mass transfer will occur through two mechanisms. Primarily the movement of moisture internally within the food and secondly, the movement of water vapor from the food surface as a result of external conditions of temperature, air humidity, air flow and area of exposed surface.

Akhila and shareena (2009) conducted experiment on matured jackfruit with three selected temperatures of (50, 60 and 70°C). Rehydration studies were conducted on dried jackfruit samples to standardise the drying temperature. Results reported that drying of treated samples at 70°C resulted in darker products. The rehydration ratio, colour and brightness of the treated samples dried at 60°C were found to be good and average hardness of sample was 24.262 kg.

Saxena *et al.* (2012) evaluated the kinetics of colour and carotenoids changes in jackfruit bulb slices during hot air drying at 50, 60 and 70°C.

Visual colours as well as total carotenoids (TC) content were found to be influenced by the drying process. Combination of Hunter L × b colour parameter contributed significantly to the perception of colour change as compared with other combinations. Yellow hue of the samples showed a decreasing behaviour at all drying temperatures, while the total colour difference and non- enzymatic browning increased with the increase in drying period.

A study conducted by Saxena *et al.* (2012) for drying kinetics of colour and carotenoids degradation in jackfruit bulb slices during hot air drying at 50, 60 and 70°C. It was concluded that as drying time and temperature increased, the jackfruit bulb slices during drying lost their yellowness and turned to brownish colour.

Effect of different hot air temperature on drying time of jackfruit bulbs during convective hot air dehydration was investigated by Taib *et al.* (2013). Total drying time to dehydrate the jackfruit bulbs with hot air temperature of 60, 70, and 80ºC were 1200, 1100, and 720 min, respectively. It was observed that more drying time was spent to reduce small amount of remained moisture in the dehydrated material during last stage of convective hot air dehydration.

Kaushal and Sharma (2016) conducted the experiment on osmo-convective dehydration kinetics of jackfruit. The jackfruit samples were osmotically pre-treated with 15% salt solution and convectively dehydrated at air temperatures of 50, 60 and 70°C in a tray dryer at constant air velocity of 1.5 m/s in perforated trays. Results reported that drying process took place in falling rate period. The sample compared to 50 and 70ºC drying temperatures, samples dried at 60ºC was found better in colour.

2.4.1 Drying Kinetics

Convective drying is considered as a heat and mass transfer process where water is transferred by diffusion from inside of the food material to the food air interface and from the interface to the air stream by convection.

Mwithiga and Olwal (2005) undertook an experiment to study the effect of air temperature and sample thickness on the drying kinetics of kale using a convective dryer at a fixed airflow rate of one m/s and drying air temperatures of 30, 40, 50 and 60°C. The drying rate increased with drying air temperature but decreased with layer thickness. The effective diffusivity for 10 mm thick layers was found to increase with the drying air temperature and ranged between 14.9 and 55.9×10^{-10} m^2/s. Four drying models were developed using the experimental data. Among all the models Modified Page model was found to be most suitable model for estimating the drying curve over the experimental temperature range.

Giraldo-Zunig *et al.* (2006) conducted experiment on jackfruit drying to reach a dry basis moisture content of 21.3%. Samples dried in convective vertical tray dryer with dry bulb temperatures of 50, 60 and 70°C and drying time 9.92, 6.1 and 4.75 h, respectively. Jackfruit drying curves were obtained using the Fick diffusion and Page models, these were fitted to the experimental data of drying velocity using non-linear regression analysis. The coefficient of determination obtained for the Fick model was 0.99.

Thin layer drying characteristics of apple pomace on hot air convective dryer was evaluated by Wang, (2007). The drying experiments were carried out at 75, 85, 95 and 105ºC and at the air velocity of 1.20 ± 0.03 m/s. Drying behavior was tested using different mathematical models. Results reported that the better prediction for moisture transfer was obtained in Logarithmic model. The drying process took place in two falling rate periods; the effective diffusivities in the second period were about six times greater than that in the first period.

Meisami-as *et al.* (2010) carried out experiment for thin layer drying kinetics of apple slices (variety-Golab) in a convective dryer. Drying characteristics of apple slices were determined at air temperatures of about 40 to 80°C, air velocity of 0.5 m/s and thickness of slices 2, 4 and 6 mm. Thirteen thin-layer drying models were fitted to the experimental data. The fitting ability of the models is compared using the root mean square error, chi- square and modeling efficiency. It was reported that as decreasing in slice thickness, increasing the drying air temperature and results shorter drying times. Among all the fitted models for describing the drying curves of the apple slices Midilli and Kucuk (2003) model was found to be the best model.

Tunde-Akintunde and Ogunlakin, (2013) conducted experiment on drying characteristics of pretreated and untreated pumpkin in a hot-air dryer at air temperatures within a range of 40–80°C and a constant air velocity of 1.5 m/s. The drying process was observed in the falling-rate drying period. The experimental

drying data was fitted to Exponential, General exponential, Logarithmic, Page, Midilli-Kucuk and Parabolic models. Statistical validity of models was tested and determined by non-linear regression analysis. The Parabolic model had the highest R^2 and lowest χ^2 and RMSE values.

Kabiru *et al*. (2013) carried out experiment on drying kinetics of fresh mangoes, dried at three different temperatures of 60, 70 and 80ºC with 3, 6 and 9 mm slice thickness and drying air velocity of 3.5 m/s. values were fitted to four drying models namely Newton, Page, Modified Page and Henderson and Pabis. The drying process has taken place in falling rate period and Page model described the drying behavior of the mango slices satisfactorily with R^2 value of 0.990.

Effect of pretreatment (0.5% citric acid solution) and drying air temperature (40, 50, 60, and 70ºC) on drying characteristics of button mushroom slices in a cabinet dryer was investigated by Doymaz, (2014). The experimental results reported that the drying temperature and pretreatment have significant effects on the moisture removal from mushroom. Rehydration ratio of pretreated samples was higher than that of control ones. Among all four kinds of classical models the logarithmic model was considered as the best for representation drying of mushroom.

Drying kinetics and effect on shapes of jackfruit was carried out by Gan and Poh (2014). Drying curves of three different shaped jackfruit slices were obtained using a convective oven at 40, 50, 60 and 70ºC. Modified Midilli-Kucuk Model was found to be the best kinetic model for drying of jackfruits at all temperatures. Drying was found to be most efficient at 50ºC using the square shaped slices with a R^2, RMSE and SSE value of 0.9984, 0.01127 and 0.002668, respectively.

Rahman *et al.* (2015) studied the effects of temperature on the drying of *Nephelium Lappaceum* (Rambutan) at drying temperatures of 40, 50, 60, 70 and 80°C for 24 h, and the drying kinetics were evaluated. Five thin layer mathematical models

such as Lewis, Page, Handerson and Pabis, logarithmic and two-term model were considered and experimental data were fitted to it. These models were evaluated by comparing the coefficient of determination (R^2), chi square (χ^2) reduced sum square error (SSE) and root mean square error (RMSE). The experimental data best fit to the logarithmic model.

Mathematical model of thin layer drying behavior of ripened jackfruit (*Artocarpus heterophyllus L*) was presented by Saxena and Dash (2015). Jackfruit bulbs dried at four different temperatures *i.e.,* 50, 60, 70 and 80°C using a tray dryer. Dry basis moisture content values obtained at varying temperature were fitted for 14 different thin-layer drying empirical models. Among the entire fitted models Middilli model was found to be most suitable model representing the drying behavior of jackfruit.

2.5 DEVELOPMENT OF BLANCHER

Timbers *et al.* (1984) developed a new prototype blanching system for food industry. Results demonstrated that, new blanching system was more energy efficient compared to water and conventional steam blanching. In the developed blancher, more improvements were observed in performance characteristics of steam use and lower effluent generations. Retention of nutrients was improved with the new system compared with water blanching. An evaluation of vegetable products indicated that texture, aroma and colour were equal to the quality obtained using conventional blanching processes.

Bhatt (2009) developed a steam blancher for cauliflower florets. Fresh cauliflower was subjected to hot water and steam blanching at 95°C for 5min and 240 kPa for 4 min, respectively. Yield of steam blanched sample was higher (9.7%) than hot water blanched samples (8.24%) in terms of colour, flavor rehydration ratio retention. Organoleptic quality of steam blanched samples was better in both

rehydrated and dehydrated samples. Energy consumption for steam blanching was 300.9 KJ/kg which is less than hot water blanching was 334.9 kJ/kg.

A new experimental blancher for steeping of polished rice and parboiled rice was developed and optimised by Bevilacqua *et al.* (2012). Results obtained indicated that it was more efficient and reliable from the technological point of view since it is both functional and energy efficient.

2.6 DEVELOPMENT OF DRYERS

Darabi *et al.* (2015) developed a cabinet dryer with separate entrances for the trays for ensuring the uniformity of dried product. Performance evaluation of new pilot size dryer was conducted for lemon fruit with initial moisture content of 84% (w.b.). The experimental results illustrated an even distribution of air velocity and temperature throughout the dryer. The newly developed drier was superior in terms of air flow distribution, uniformity among the trays, rate of drying in different trays, and electrical energy consumptions, when compared to the existing machines.

Cabinet tray dryer for agricultural and bio-materials was developed by Akpan *et al.* (2016) to reduce the agricultural material wastage and to improve the storage conditions. It consists of mainly three units *i.e.*, drying chamber, blower and heat exchanger. The performance evaluation of dryer was conducted for three different samples like okra, pepper and groundnut with an average drying chamber temperature of 50°C for safe drying of the produce with drying time of 9 h. The capacity of drying chamber was 60.3 kg per batch with a thermal efficiency of 76.9% and drying rate of 0.041 kg/hr, at relative humidity of 35%.

2.7 PRODUCT QUALITY PARAMETERS

2.7.1 Moisture Content

Drying performance of ginger in a cabinet dryer was studied by Loha *et al.* (2008). Ginger slices were dried at three different hot air inlet temperatures of 40, 50 and 60^{o}C and air flow rate of 900 m^3/h. Reduction of moisture content from 82-88% (w.b.) to 8-10% (w.b.) was observed that the maximum drying rate was achieved at 60°C without any quality loss. To dry ten kg of ginger slices 5 h was required without affecting the quality of the product.

Abano *et al.* (2011) investigated the effects of different pretreatments on drying characteristics of banana slices. Banana samples of 5 and 7 mm thick slices were pretreated with four different pretreatments such as ascorbic acid, lemon juice, salt solution, honey dip and a control for 10 min. Pretreated banana slices were dried in a cabinet dryer at temperatures of 60°C and 70^{o}C. The moisture content of the fresh ripe bananas for both the untreated and treated samples was found to be in the range of 75-77% (w.b.) which reduced to 16.8 to 27% after 16 h of air drying.

Saxena *et al.* (2012) opinioned that jackfruit contains average moisture content of around 76 ± 0.02% (w.b.). Moisture removal was required to reduce the water activity and growth of microorganisms, and also allowed safe storage over an extended period, thus extending the shelf-life.

2.7.2 Texture

In texture analysis, firmness and toughness are most important textural attributes of jackfruit fruit crisps.

Conventional high temperature, short time blanching compared to the low-temperature longtime blanching for better quality retention of mung bean shoots. Compared to high temperature short time blanching, low-temperature long time

blanching enhanced the firmness and reduced the nutritional and flavour losses of the product (Taylor *et al.,* 1981; Canet and Hill, 1987).

Ramana and Taylor (1994) concluded that texture was another important parameter connected to product quality, which was related to the structure of foods. Textural characteristics also depend on chemical and biophysical characteristics of the products (Mohsenin, 1986; Thiagu *et al.,* 1993).

Pritty and Sudheer (2012) carried out an experiment using *'varikka'* variety of tender jackfruit. At three minutes of blanching process minimum reduction in firmness (18%) and toughness (13%) was observed, and at seven minutes of blanching maximum reduction in firmness (43%) and toughness (32%) was observed.

2.7.3 Vitamin C

Erdman and Klein (1982) reported that as ascorbic acid is susceptible to heat, it is difficult to retain vitamin C during the dehydration of foods. The loss of ascorbic acid was depends on many factors including the presence and type of heavy metals, such as copper and iron, light, pH, water activity level in the product, dissolved oxygen, and the drying temperature.

Chin and Dudek (1988) studied that, vitamin C was relatively unstable to heat, oxygen and light. The retention of vitamin C was often used as an indication of the quality of processed foods. If ascorbic acid was retained, other nutrients were well retained.

Vitamin C was a water-soluble free radical scavenger. The daily recommended dietary allowance was 60 mg. Jackfruit was a good source of vitamin C. In young jackfruit 12 to 14 mg vitamin C was present per 100 g (Narasimham 1990).

Moser and Bendich (1991) estimated the ascorbic acid degradation which cause the quality loss and colour formation of product. The colour formation can also occurred by other ways such as browning and pigment degradation. Ascorbic acid degradation and colour formation were observed during thermal processing.

2.7.4 pH

pH is the negative logarithm of hydrogen ion concentration and it determines the amount of acids present in the fruit.

Antarkar, (1991) evaluated the pH of jackfruit carpels decreased from harvest to ripening stage. The pH of jackfruit carpels at harvest stage was 5.3 to 5.7. On ripening, it was decreased in firm flesh and soft flesh types of jackfruit and ranged between 5.2 and 5.4 respectively.

Jackfruit firm flesh showed initial decline in pH till 45 days of fruit set (4.98), after reached to maximum at 90 days after fruit set (5.73) and again declined (5.47) towards full maturity Sawant, (2000). In soft flesh jackfruit, the gradual increase in pH was noticed upto 90 days after fruit set (5.84). The pH rapidly declined towards full maturity (4.87) in soft flesh jackfruit.

Patil (2003) reported that, the pH values for bulbs, perigones, rind, core and seed of firm flesh jackfruit at harvest and ripe stage were 4.86, 4.31, 4.61, 4.26, 4.23 and 4.57, 4.18, 4.11, 4.21, 4.21, respectively. The pH values in above different parts of soft flesh jackfruit at harvest and ripe stage were 4.85, 4.31, 4.83, 4.97, 4.84, and 4.81, 4.27, 4.45, 4.37, 4.66, respectively. Irrespective of type of jackfruit pH value of all parts of jackfruit was decreased on ripening.

2.7.5 Rehydration Ratio

The dehydrated fruits and vegetable products could also be further processed or consumed after rehydration reported by Lewicki, (1998). Hot air-dried jackfruit

bulbs crisps showed lower rehydration ratio because of the formation of compact tissue structure during drying. In general, as increase in the hot air drying duration, the samples recorded corresponding increase in shrinkage and hardness, which could be responsible for the lower rehydration ratio.

Akbari and Patel (2006) determined the rehydration quality of the dehydrated onion flakes. Studies indicated that the rehydration ratio was decreased with the increase in temperature, increases in thickness of slice and decrease in velocity of air.

Dehydration of jackfruit bulbs by microwave vacuum (58 W) and convective hot air (60ºC) drying was carried out by Taib *et al.* (2013). Results showed that microwave vacuum dehydration showed better rehydration ability compared to hot air dried samples. The better rehydration ability could be due to the higher porosity created by reduced pressure.

2.7.6 Total Soluble Solids

The total soluble solid is one of the qualities determining status of the fruit. It is one of the reliable maturity indices in many fruits. TSS includes sugars, organic acids and some minerals.

Antarkar (1991) reported that TSS of soft flesh jackfruit at harvest and ripe stage were 6°B and 25ºB, respectively. Parab (1992) noticed that TSS content of firm flesh jackfruit at harvest and ripe stage were 5 and 24ºB, respectively. However, the same in soft flesh type of jackfruit was 6 and 22ºB, respectively.

Patil (2003) revealed that, TSS content in bulbs of firm flesh and soft flesh jackfruits at harvest was 5 and 6ºB, respectively. At harvest stage, firm flesh jackfruit bulbs recorded more TSS (26ºB) than the soft flesh jackfruit bulbs (23ºB). The bulbs of both the type of jackfruit contained significantly highest TSS than perigones and rind.

Total soluble solids content was higher when harvested after fourteen weeks of fruit set (16.96°B). Whereas it was observed lower at eleven weeks of fruit set (11.72°B).

Patil *et al.* (2014) conducted experiment on effect of pre-treatments on physico-chemical composition of dehydrated jackfruit chips during storage at ambient temperature. Among all treatments, samples treated with ascorbic acid and blanched was recorded maximum TSS content of 13.49ºB irrespective of storage period. The TSS increased with increase in storage period.

2.7.7 Microbial Analysis

Microbial quality of intermediate moisture banana stored at 0ºC and 37ºC was reported by Ramarjuna and Jayaraman (1980). Results explained that at 0ºC the total plate count (TPC) was 250 - 300 colonies/g but at room temperature 37ºC it was negligible and product was microbiologically safe for direct consumption.

Adams and Moss (2000) studied that the temperature in the driers might kill some of the bacteria, but still many would survive and even get more heat resisted during the process. The enhanced humidity during night time might cause moisture absorption of product from the surroundings.

Patricia *et al*. (2007) observed the influence of blanching treatment on inactivation Salmonella during drying and storage of carrot slices. The carrot slices were subjected to the treatments such as steam blanching (88°C, 10 min), water blanching (88°C, 4 min), blanching in a 0.105% citric acid solution (88ºC, 4 min), or blanching in a 0.21% citric acid solution (88°C, 4 min), and were dried for 6 h at 60ºC and stored for 30 days. Bacterial populations were reduced immediately following steam, water or citric acid blanching. Results suggest that blanching of carrot slices, particularly blanching in 0.21% citric acid, before drying enhanced inactivation of Salmonella during dehydration and storage.

Robertson (2006) reported that causes of spoilage in foods due to microorganisms these can be divided into two factors intrinsic and extrinsic. The intrinsic factors were pH, water activity, and nutrient content, while storage temperature, relative humidity of the environment and concentration of gases in environment were the extrinsic factors.

Pritty *et al.* (2013) conducted experiment on tender jackfruit samples for microbial analysis at two pasteurised (90 and 100°C; F_0 values 8, 10) and two sterilised temperatures (110 and 121°C; F_0 values 1, 2). The results concluded that microbial counts were within permissible limit upto 60 days of storage in case of tender jackfruit pasteurised for $F_0$10 and sterilised for $F_0$1 at 121°C and F_0 2 for both 110°C and 121°C temperatures and safe for further storage.

Padmavathi (2015) studied the effect of packaging and storage period of vaccum dried ripened jackfruit bulbs on microbial load. It was reported that at the end of 30 days of storage period microbial load was within the permissible limit (< 50/g) and the LDPE 100 micron packaging bags was found to be best with least microbial count.

The effect of preservatives and storage period on the microbial analysis for sterilised and pasteurised retort packed tender jackfruit samples were estimated by Praveena, (2015). The results of microbial analysis revealed that both the sterilised and pasteurised samples were microbiologically safe at 90 days of storage period. The microbial load in terms of bacteria, yeast and fungi were within the permissible limits *ie.*, zero cfu/g.

2.7.8 Sensory and Storage Studies

The role of sensory evaluation studies to assess the acceptability of a food product. Sensory evaluation tests provide information and guidelines for new product development and to achieve, optimise of product quality. Sensory evaluation provides

the first opportunity for feedback on a new product (Rao *et al.*, 1997). Sensory attributes like crispiness, colour, flavour, and overall acceptability, metal foil pouches were found most suitable for packaging jackfruit chips.

Saxena *et al.* (2009) carried out research on multi-target preservation jackfruit bulbs in pitted and pre-cut form. Samples were subjected to technique involving water activity (a_w) regulation, acidification, and in-pack pasteurization as the hurdles. Processing variables as osmotic concentration, temperature, and duration of immersion, osmotic dewatering process was optimised using response surface methodology. The shelf-life of multitarget preserved high moisture jackfruit bulbs was found to be 8, 6 and 4 months under the respective storage temperatures of 6°C, ambient, and 37ºC.

A study was conducted by Manikantan *et al.* (2014) on storage stability of banana chips and its quality evaluation. Overall acceptability score gradually reduced with storage period of the 0-120 days. The initial overall acceptability score of banana chips was 8.0 and it ranged between 5.4 and 6.6 during storage period.

Patil *et al.* (2014) studied the effect of different pretreatments and storage of dehydrated (55 ± 2°C) jackfruit chips at ambient temperature. Dehydrated chips stored in ambient condition for period of 0, 30 and 60 days. Slices pretreated with blanching and ascorbic acid of 0.4% stored for 60 days recorded maximum overall acceptability score of 6.91. Which clearly indicated that its suitability for making good quality chips and also for storing them for 60 days at ambient conditions without much loss of sensory and nutritional qualities of chips.

Development and quality evaluation of ripe jackfruit bulb powder carried out by Swami *et al.* (2016). Bulbs were pretreated with three different osmotic treatments using sugar solution of 60, 70 and 80°B. Osmotically treated bulbs were dried in a convective hot air dryer and tray dryer at 60ºC. Pretreated and dried samples were packed using three packaging materials such as pet bottles, transparent poly pouch

and met pet poly pack and kept for storage studies. Results obtained that after 12 months of storage jackfruit bulb powder packed in met pet poly pack with osmosis of Jackfruit bulbs at 70°B sugar solution and dried at 60°C in tray dryer revealed good results with respect to chemical and sensory quality.

The sensory evaluation was conducted by Pritty *et al.* (2013) for different treatments on different organoleptic properties for pasteurised and sterilised tender jackfruit samples. From the sensory score it was observed that thermally processed pasteurized (19 min) tender jackfruit having citric acid as filling solution found to be the best and found. The best judged sample scores maximum in terms of organoleptic traits colour, flavour, texture and overall acceptability, and found to be significant.

Praveena, (2015) evaluated the quality parameters in terms of colour, flavour, texture and overall acceptability by Kendall's coefficient of concordance test for sterilised and pasteurised tender jackfruit samples. Results reported that 0.3% citric acid blanching and 0.3% citric acid preservative as filling solution was found to be best in terms of quality parameters upto 90 days of storage. The samples were significant for all the parameters except for flavour.

2.8 PACKAGING MATERIALS

Callegarin *et al.* (1997) reported that to preserve quality of the banana chips during the storage proper packaging is most important for marketing.

Sandhu and Bawa (1993) observed that potato chips packed in aluminum foil of 0.02 mm thickness and polyethylene (100 μm) and storage at ambient conditions (14-34°C and 45-77% RH). Potato chips stored in aluminum foil had very good acceptability even after 90 days of storage, while the chips stored in polyethylene remained acceptable only up to 60 days of storage.

Sabikhi and Tiwari (1999) reported that chips were sensitive to water vapour (loss of crispiness), light (rancidity of fat) and mechanical damage. Therefore, packaging material for chips must be light proof and impermeable to water vapor and gases.

Aluminium foil exhibited better moisture barrier than polyethylene and laminated paper reported by Bal *et al.* (2002). When potato chips fried in sunflower oil and stored under ambient conditions with aluminium foil as packaging material there is no changes were observed upto 90 days of storage.

Molla *et al.* (2008) reported the effect of packaging materials on the storage of jackfruit chips. Chips were packed in three packaging materials *i.e.*, metalex foil pouch, high density polyethylene and polypropylene pouch. By considering moisture content (%), weight gain (%), quality aspects and sensory attributes like crispiness, colour, flavour and overall acceptability, metalex foil pouch was found most suitable for packaging of jackfruit chips compared to high density polyethylene and polypropylene pouch. The prepared chips could be stored at ambient condition keeping in metalex foil for two months without loss of organoleptic quality.

The jackfruit of two genotypes *Tane Varikka* and *Muttom Varikka* slices were fried and chips were stored in three different packages *viz.*, polyethylene, polypropylene and aluminium laminate for about sixty days duration at ambient condition (Satishkumar and Karthik, 2015). The jackfruit chips stored in Polyethylene and Polypropelene bags of 300 µm recorded considerably higher moisture content was observed during two months of storage due to migration of moisture into the chips from surrounding gases. The storage period increased to three months decrease in free fatty acids of jackfruit chips was observed. The colour attributes such as *a** and *b** values of jackfruit chips varied as the storage period increased which is mainly due to complex changes in biochemical properties.

CHAPTER III
MATERIALS AND METHODS

This chapter describes the fabrication and development of a blancher cum dryer unit for jackfruit. Process parameters adopted and methodologies used for quality evaluation of the dried jackfruit are also appended.

3.1 JACKFRUIT PROCUREMENT AND SAMPLE PREPARATION

Matured, unripe jackfruits (*Artocarpus heterophyllus L*), of Moraceae family which belongs to the '*Varikka*' variety were procured from the KCAET Instructional Farm, Tavanur (May-July, 2016). The collected jackfruits were washed in tap water, peeled and cored using corer cum cutter. Jackfruit bulbs were separated from the rind using a stainless steel knife. Seeds were separated from bulbs and sliced using a jackfruit slicer to obtain slices of uniform thickness. The average capacity of the jackfruit slicer was found to be 50 kg/h. The average thickness of slices was found to be 7.62 ± 0.33 mm.

3.2 DEVELOPMENT OF A BLANCHER CUM DRYER

A prototype blancher cum dryer with dimensions of 1140 × 900 × 2000 mm was developed and fabricated using a SS 304 sheet (2500 × 1250 × 1 mm) and SS tubes (square pipe 50 mm) by TIG welding. The blancher cum dryer mainly consists of steam chamber, drying chamber, frame assembly, water heaters, air heating coils and blowers. Frame assembly was constructed with SS square pipes of 50 mm joined by TIG welding. The whole frame was divided into twelve compartments to accommodate twelve stainless steel trays fabricated using the SS 304 material to place the product uniformly. Steaming chamber was provided at the bottom for generating steam. Two blower fans were provided to enhance the convective heat transfer inside the drying chamber, and to drive out the exhaust hot humid air from the drying chamber. Temperature sensors were provided at inlet, drying chamber and exhaust to

monitor the drying process parameters. A temperature controller was used to study the drying kinetics of jackfruit at various drying temperatures. The entire blancher cum drier unit was fabricated using SS 304 sheet material as shown in the (Plate 3.1).

3.3 SPECIFICATIONS OF THE BLANCHER CUM DRYER

The isometric view, sectional and front view of a developed blancher cum dryer was shown in Fig. 3.1, 3.2 and 3.3. The components of the blancher are presented in Table 3.1.

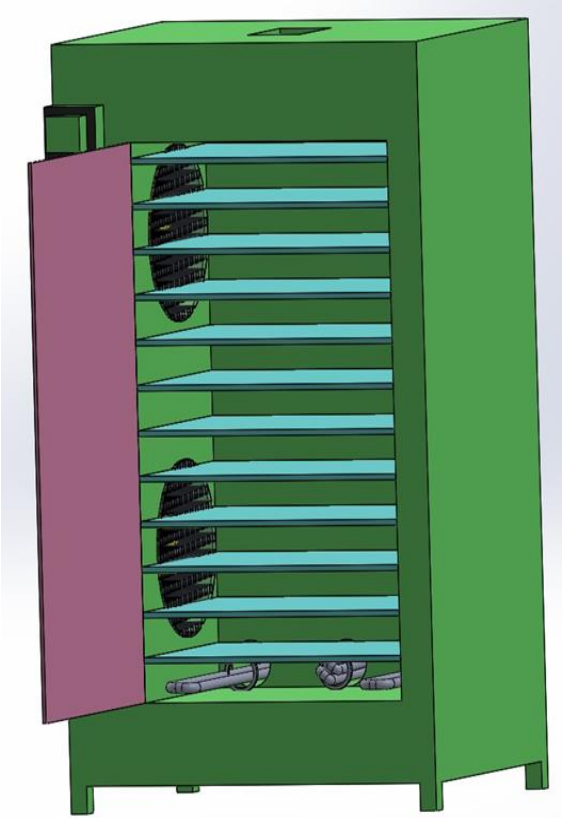
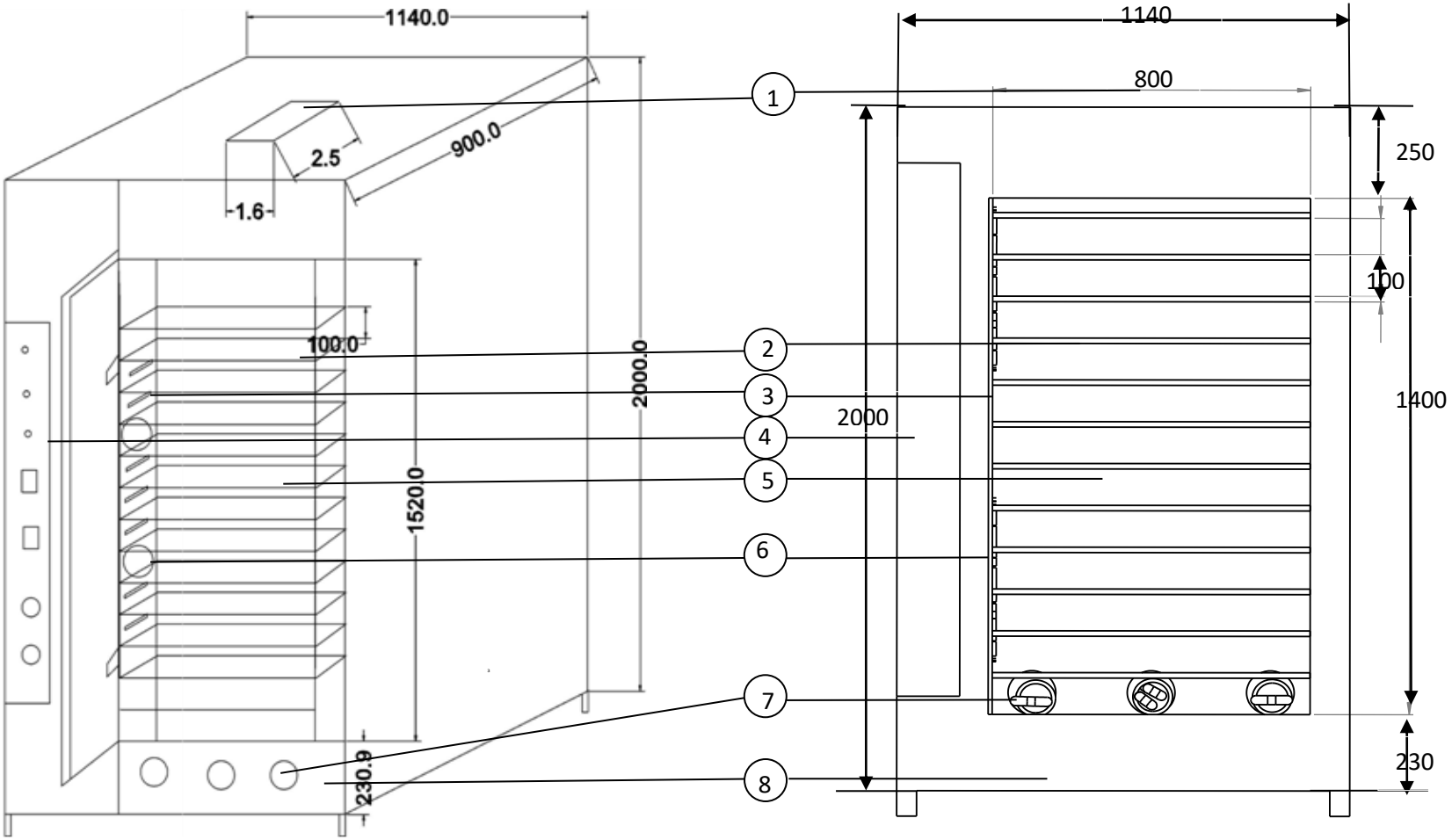


Figure 3.1 Isometric view of the dryer

Plate 3.1 Blancher cum dryer

Table 3.1 Components of the blancher cum dryer

Sl. No.	Components	Specifications
1	Steaming chamber • Dimensions • water tank capacity	 1100 × 900 × 230 mm 60 *l*
2	Water heaters • Numbers • Capacity	 3 Two heaters with 4000 W each and one heater with 2000 W
3	Drying chamber • Dimensions • Volume of dryer	 760 × 900 × 1770 mm 1.210 m^3
4	Frame assembly • Dimensions • No. of Trays • Dimensions • Area of the tray	 600 × 800 × 1400 mm 12 trays 530 × 730 × 20 mm 0.39 m^2
5	Blowers • Numbers • Capacity • Air velocity	 2 60 W each 1400 rpm
6	Air heaters • Numbers • Capacity	 6 1000 W
7	Air discharge • Dimensions	 250 × 160 mm
8	Drain valve • Diameter of the valve	 27 mm
9	Material for construction	SS 304 sheet



All dimensions are in mm (Scale: 1:10)

Figure 3.2 Sectional view of the dryer

Figure 3.3 Front view of the dryer

1- Air exhaust 2- Trays 3- Air heating coils 4- Control panel

5- Drying chamber 6- Blowers 7- Water heaters 8- Steaming chamber

3.3.1 Drying Chamber

A rectangular drying chamber was fabricated using SS 304 material. Drying chamber was provided with outer dimension of 760 × 900 × 1770 mm and volume of the fabricated dryer was 1.210 m^3. The frame was constructed in rectangular shape with dimensions of 600 × 800 × 1400 mm using SS square pipes of 50 mm thickness joined together by TIG welding in such a way as to give rigidity to the dryer. Aluminium bars with one inch were welded to the sides to give base for the trays. The frame was divided into twelve compartments to accommodate twelve perforated trays. Two angle bars with 800 mm length were welded to the drying chamber horizontally to provide base for the frame assembly. Each tray was provided with dimensions of 530 × 730 ×20 mm and an area of each tray was 0.39 m^2 to place the product. Twelve aluminium trays were stacked evenly at distances of 100 mm apart for uniform distribution of air, each containing a pores with a 5 mm dia. A door was provided with locking arrangement for loading and unloading of the trays in the drying chamber. The door was lined with sealing rubber to make it airtight and to avoid loss of steam.

3.3.2 Steaming Chamber

Rectangular shaped steam chamber was fabricated using SS 304 sheet with dimensions of 1100 × 900 × 230 mm at the bottom of the drying unit. Chamber was provided with water chamber capacity of 60 *l*. Two heaters with a capacity of 4000 W each and one with a capacity of 2000 W were provided at the bottom of the steam chamber for generating the steam.

3.3.3 Blowers

The main purpose of blower was to transfer hot air from heat exchangers to the drying chamber. The blower was selected based on the total volumetric flow rate

of air per second through the inlet ports. Two blowers with a speed of 1400 rpm and capacity 60 W each were placed perpendicularly to the trays and it could be controlled to vary the air velocity. Hot air was forced through the chamber over the trays at an air velocity of 2.8-3.2 m/s. The blower was made of a stainless steel with a fan diameter of 304.8 mm and each was operated with 0.5 hp motor. Blowers were arranged in between the air heating coils.

3.3.4 Air Heaters

Six finned tubular heaters were made of stainless steel and arranged in between the blowers. Two heaters were provided at the top and bottom and three heaters were provided between the blowers. Six finned tubular heaters were provided with a capacity of 1000 W each, to heat the incoming fresh air from ambient temperature to more than 100ºC. A temperature controller was fitted over the controller panel to control temperature.

3.3.5 Drain Valve

Drain valve was provided at the bottom of the steaming chamber with diameter of 27 mm. Main purpose of the drain valve was to remove the water which was left after steam production.

3.3.6 Control Panel

Control panel consists of a LED indicator, switches (main switch, heater and coils switch), temperature sockets, fuses, digital temperature controller, digital temperature indicator and motor switch.

3.3.7 Air Discharge

Air after passing in the drying chamber, was finally discharged through a discharge duct. Air discharge duct with rectangular cross section was projected. The

air discharge was provided with a cross section of 250×160 mm^2 and dragging closure was provided for easy removal of condensed steam and moisture.

3.4 Performance Evaluation of the Blancher cum Dryer

The performance evaluation of the blancher cum dryer comprised of assessment energy required for steam production, blanching, and drying. The capacity of the machine was evaluated at three different loading rates at various thickness and three different temperatures as independent parameters and time required for drying as dependent parameter. Energy utilised for production of steam and drying the product was measured using AC Static Watt-hour meter. Air velocity of the blowers was calculated using air anemometer (LT Lutron AM 4201) meter per second.

Quality parameters of the dried samples such as colour, pH, total soluble solids, vitamin C, texture, total plate count and crude fibre content were evaluated for the fresh and dried samples. Comparison of developed unit with existing method (*i.e.*, drying and blanching in separate units) in terms of capacity (output in kg/h), energy utilised, time consumed, cost of labour, cost of fabrication and quality of dried product was carried out. Fig. 3.4 shows the flow chart for steam blanching and convective drying of jackfruit slices.

3.4.1 Capacity of the Dryer

Steam blanched and pretreated slices were loaded in twelve trays which were arranged in frame assembly. Samples were placed at three different loads L1, L2 and L3 with loading capacity of 3.8, 4.8 and 5.8 kg/m^2 respectively. Under full loading conditions capacity of blancher cum dryer at all three loads was 18, 23 and 28 kg.

3.5 STANDARDISATION OF BLANCHING TIME AND TREATMENT

To prevent browning reactions, two kg of solution was required to dip one kg of jackfruit slices for about 10 min (Molla *et al.,* 2008), the solution containing

various preservatives in different proportions. Pretreatments such as (citric acid, potassium metabisulphate and turmeric powder) were given prior to steam blanching for preventing enzymatic browning of light coloured food (FAO, 2004). Based on the preliminary studies, blanching temperature (80°C) and blanching time (6, 7, 8 and 9 min) were selected. Pretreatments also enhance the drying operations such as the drying time, yield and to obtain good quality dried product (Piga *et al.*, 2004). Based on the enzymatic inactivation blanching time and pretreatments were standardised for jackfruit. Steam blanching was usually used for cut and small products, and requires less time than water blanching because the heat transfer coefficient of condensing steam is greater than that of hot water. In addition, leaching of water soluble nutrient was reduced compared to water blanching (John *et al.*, 2004).

Different pretreatments for this study were as follows:

C1: control (Unblanched and untreated)

C2: steam blanching+0.1% citric acid+ 0.1% KMS+ 0.1% Turmeric powder

C3: steam blanching+0.1% citric acid+ 0.1% KMS+ 0.3% Turmeric powder

C4: steam blanching+0.1% citric acid+ 0.1% KMS+ 0.5% Turmeric powder

C5: steam blanching+0.2% citric acid+ 0.1% KMS+ 0.1% Turmeric powder

C6: steam blanching+0.2% citric acid+ 0.1% KMS+ 0.3% Turmeric powder

C7: steam blanching+0.2% citric acid+ 0.1% KMS+ 0.5% Turmeric powder

C8: steam blanching+0.3% citric acid+ 0.1% KMS+ 0.1% Turmeric powder

C9: steam blanching+0.3% citric acid+ 0.1% KMS+ 0.3% Turmeric powder

C10: steam blanching+0.3% citric acid+ 0.1% KMS+ 0.5% Turmeric powder

The pre-treatment time was standardised based on inactivation of peroxidase and catalase enzyme in different combination of pretreatment, texture and colour attributes of the samples. After the blanching process, the samples were cooled immediately using forced air in order to avoid overheating.

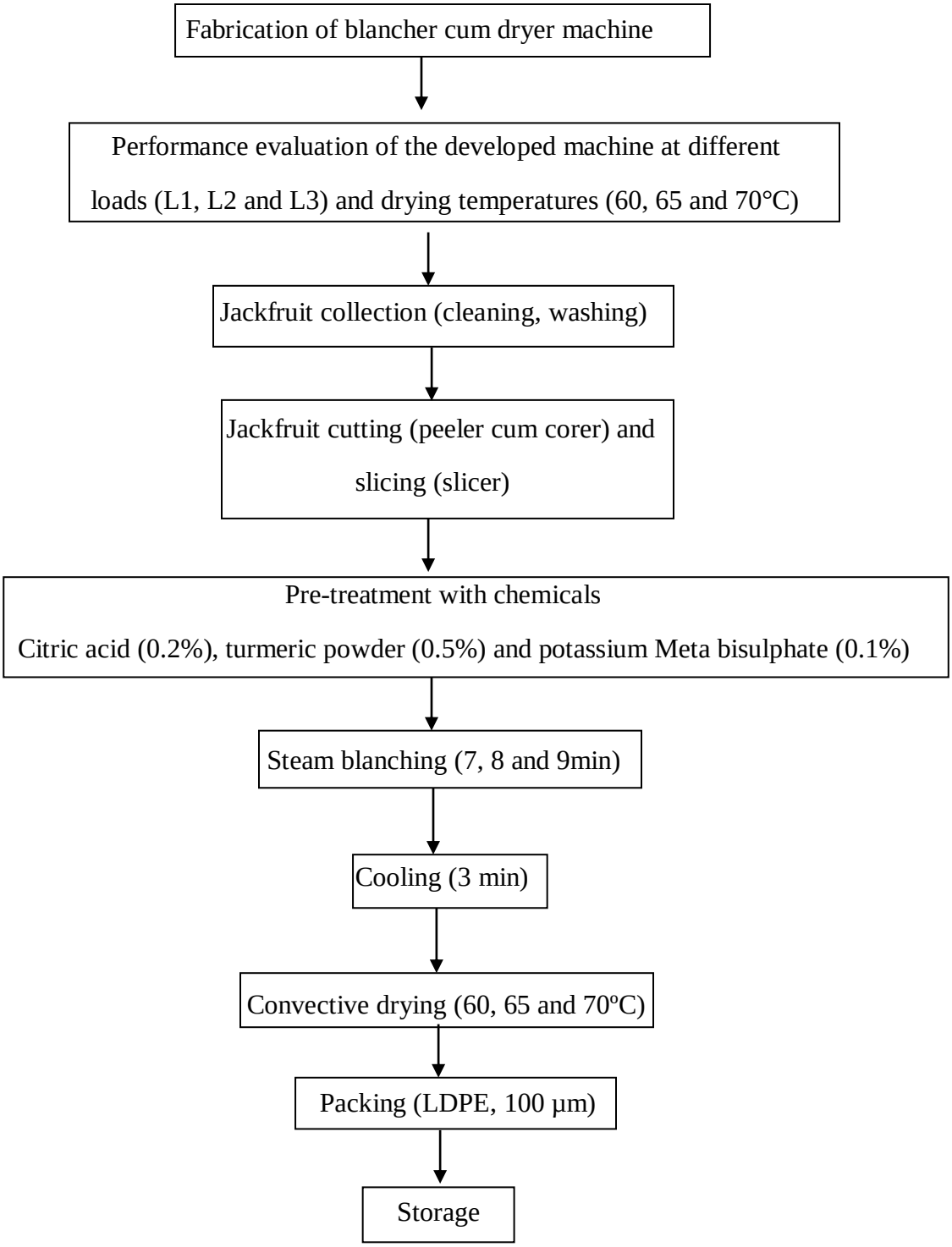


Fig. 3.4 Flow chart for steam blanching and convective drying of jackfruit slices

3.5.1 Peroxidase Test

The matured jackfruit bulbs were sliced using a slicer and about ten to twenty grams of samples were crushed in a porcelain bowl immediately after blanching. The crushed sample was taken in a test tube and 20 ml distilled water was added. Glycol (1%) and hydrogen peroxide (0.3%) solutions were added to the sample. Glycol solution (1 ml) and hydrogen peroxide solution (1.6 ml) were poured into the test tube and the samples were mixed thoroughly. A rapid and intensive brown-reddish colour at the surface of tissue appears within 5 min indicated a high peroxidase activity. The gradual appearance of a weak pink colour indicated an incomplete peroxidase inactivation or low peroxidase activity. If there was no colour development after 5 min, the reaction was negative and the enzymes were inactivated (Shivhare *et al.*, 2009).

3.5.2 Catalase Test

Matured jackfruit bulb slices (approximately 2 g) were crushed in distilled water and left for about 15 min. Then 0.5 ml of 1% hydrogen peroxide solution was added. A strong gas (oxygen) generation or bubble formation was observed within two to three minutes which indicates the presence of catalase, and no release of gas or no bubble formation showed the complete inactivation of catalase (Shivhare *et al.*, 2009, Pritty and Sudheer, 2012).

3.6 DRYING EXPERIMENTS WITH DIFFERENT TEMPERATURES AND LOADING

Blanched samples were dried in twelve perforated trays with air velocity of 2.8-3.2 m/s. Three drying temperatures of 60, 65 and 70°C at three different loading rates L1, L2, and L3 were followed to conduct the experiments. Drying chamber with loading of jackfruit sample is shown in plate 3.2.

Plate 3.2 Drying chamber with loading of jackfruit sample

Combination of loading rates and drying temperatures were as follows

Control: 18 kg samples at temperature of 60°C (untreated)

L1T1: 18 kg samples at temperature of 60°C

L1T2: 18 kg samples at temperature of 65°C

L1T3: 18 kg samples at temperature of 70°C

L2T1: 23 kg samples at temperature of 60°C

L2T2: 23 kg samples at temperature of 65°C

L2T3: 23 kg samples at temperature of 70°C

L3T1: 28 kg samples at temperature of 60°C

L3T2: 28 kg samples at temperature of 65°C

L3T3: 28 kg samples at temperature of 70°C

The samples were dried at all the nine combinations with different temperatures at various load thicknesses. The quality parameters were determined for all the combinations initially before kept for storage studies. Among all the combinations, best loading rate and temperature was selected based on quality retention and capacity.

3.6.1 Drying Rate of Jackfruit Slices

The drying rate of jackfruit slices was calculated by using the following equation,

Drying rate (moisture evaporated/min/100g of dry matter)

$$= \frac{\text{Amount of moisture removed from the sample (g)}}{\text{Time taken (min)} \times \frac{\text{Dry matter content}}{100}} \quad \ldots 3.1$$

3.6.2 Mathematical Modeling of Drying of Jackfruit Slices

The mathematical models such as, Newton, Page, Henderson and Pabis and logarithmic models were selected on their ability to best fit the experimental data. The models are;

Newton model: $MR = \exp(-K\theta)$ …3.2

Page model: $MR = \exp(-K\theta^n)$ …3.3

Henderson and Pabis model: $MR = a*\exp(-K\theta)$ …3.4

Logarithmic model: $MR = a*\exp(-K\theta) + c$ …3.5

The moisture ratio (MR) is denoted by

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad \ldots 3.6$$

Where,

MR= Moisture ratio

M_e = equilibrium moisture content, (% d.b.)

M_t= moisture content at any time, θ (% d.b.)

M_o = initial moisture content (% d.b.)

K, n, a and c = drying rate constants

θ = drying time (min)

Four thin-layer drying models *viz.*, Newton, Page, Henderson and Pabis and logarithmic models were selected for fitting the experimental data. The constants of the selected models were estimated by non-linear regression analysis (Ramachandra and Rao, 2009). The parameters of all the models were estimated by using MATLAB R2013a software. The fit quality of the proposed models on the experimental data was evaluated using linear regression analysis using curve fitting tool in MATLAB. The statistical parameters standard square error (SSE) and root mean square error (RMSE) were calculated employing the following equations.

$$RMSE=\sqrt{\frac{\sum_{i=0}^{N}(MR_O - MR_P)^2}{df}} \quad \ldots 3.7$$

$$SSE=\frac{1}{N}\sum_{i=1}^{N}(MR_o - MR_p)^2 \quad \ldots 3.8$$

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_o - MR_p)^2}{N - z} \quad \ldots 3.9$$

Where,

MR_o = actual moisture ratio

MR_P = predicted moisture ratio

df = degrees of freedom

N = No. of data points

z = No. of constants

3.7 QUALITY ANALYSIS OF CONVECTIVE HOT AIR DRIED JACKFRUIT SLICES

3.7.1 Moisture Content (%)

The moisture content of the both fresh and dried samples of jackfruit was calculated using hot air oven method (AOAC, 2005). Both fresh and dried samples of approximately 2 g were placed in pre-dried moisture chamber in an oven. The operating temperature was 105°C for 5-6 h. After drying, the samples were taken out of the oven, cooled in a desiccator and weighed by using electronic weighing balance having a sensitivity of 0.001 g. The fresh and bone dried weights were used to determine the moisture content on wet basis.

$$\text{Moisture content (\% w.b.)} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \quad \ldots 3.10$$

Where,

W_1 = weights of empty Petri plate

W_2 = weights of sample before drying

W_3= weights of sample after drying

3.7.2 pH

The pH of the fresh and dried jackfruit samples was measured by using a digital pH meter (Make: SYSTRONICS pH meter, Model: MK VI, SR. NO. 10961). The pH meter was calibrated by the different buffer solutions. The pulp was prepared from the sample by using a processor and about 20 ml of pulp was taken in a beaker. Then the electrode of the pH meter was dipped into the sample for the test. The readings were taken as the pH value of the sample. For the next sample readings, the electrode was removed and washed properly with distilled water. The same procedure

was followed and readings were taken as the pH of sample. Each sample was replicated three times and its mean value was taken as pH of the sample.

3.7.3 Total Soluble Solids

Total soluble solid (TSS) was measured using a pocket refractometer (Make: ATAGO, Pocket PAL-1, Tokyo). Samples of about 2 g were taken and crushed using mortar and juice was taken out. One or two drops of juice were placed on the calibrated pocket refractometer for each entry, replicated thrice, and the mean was expressed in degree Brix after temperature corrections (Ranganna, 1995).

3.7.4 Colour

The Hunter's lab flex colourimeter (made by: Hunter Associates Laboratory, Reston, Virginia, USA) was used to determine the colour of fresh and dried jackfruit slices. The principle of working is by focusing the light and measuring energy reflected from the sample across the entire visible spectrum. The colourimeter has filters which rely on "standard observer curves" that measures the amount of red, yellow, green and blue colours. The colour of the jackfruit slices was measured under a colourimeter scale at 10° observer and illuminate at D_{65}. The instrument was initially calibrated with a black tile and white tile provided with the instrument for further colour measurements.

The 3-dimensional scale 'L*', 'a*' and 'b*' was used. The luminance (L*) forms the vertical axis, which indicates light - dark spectrum with a range from 0 (black) to 100 (white). In the same way, a* indicates the green - red spectrum with a range of - 60 (green) to + 60 (red) and b* indicates the blue - yellow spectrum with a range from - 60 (blue) to + 60 (yellow) dimensions respectively (Ali *et al*. 2008). In addition, *Chroma* (C) and the total colour change (ΔE) were calculated from the value of 'L*', 'a*'and 'b*'. *Chroma* indicates colour saturation of the samples which varies from dull (low value) to vivid colour (high value). The total colour change (ΔE) is the

parameter considered for the overall colour change evaluation between dried samples initially and the dried samples after storage period. Fresh jackfruit samples (L*, a*, b*) were used as the reference and a low ΔE value corresponds to a low colour change from the reference jackfruit samples.

$$Chroma,\ \ C = \sqrt{a^2 + b^2} \qquad \ldots 3.11$$

$$\Delta E = \sqrt{(L^* - L^*_0)^2 + (a^* - a^*_0)^2 + (b^* - b^*_0)^2} \qquad \ldots 3.12$$

Where,

L^*, a^*, b^* - Colour coefficient for blanched/ dried samples

L^*_0, a^*_0, b^*_0 - Colour coefficient for fresh jackfruit slices

The colour of dried jackfruit powder was measured by filling the sample in the transparent cup without any void space at the bottom. Thus, the colour value of the samples was obtained as 'L*', 'a*'and 'b*' values

3.7.5 Vitamin C

Vitamin C content was estimated by volumetric method (Sadasivam and Manickam, 1992). Dye solution was prepared using (42 mg of sodium bicarbonate and 52 mg of 2, 6, dichloro phenol indophenols dye in 200 ml of distilled water). Then about 100 mg of pure dry crystalline ascorbic acid was taken and made up to 100 ml using 4% oxalic acid to get the stock solution. The working standard solution (100 ml) was prepared by diluting 10 ml stock solution using 4% oxalic acid. After that 5 ml each of working standard solution and 4% oxalic acid was pipetted into a conical flask and titrated against the dye solution. The result point was the appearance of pale pink colour which was observed for a few minutes. The titration was repeated for 3 times to get the concordant value. The amount of dye consumed (V_1) was equal

to the amount of ascorbic acid present in the working standard solution. The sample was made into pulp and 10 ml pulp (Vs) was taken and made up to 100 ml with 4% oxalic acid solution. Then 5 ml of the made up solution was pipette into a conical flask and was titrated against the dye (V_2). The quantity of ascorbic acid (mg) present in 100 gm of sample was calculated as follows.

$$\text{Ascorbic acid (mg/100g)} = \frac{0.5}{V_1} \times \frac{V_2}{5} \times \frac{100}{V_s} \times 100 \quad \ldots 3.13$$

3.7.6 Rehydration Ratio

Rehydration is the process of refreshing the dehydrated or dried product by soaking in distilled water. About 5 g of dried sample was added to 10 ml of distilled water in Petri dishes. The surface was covered with a piece of filter paper to soak the excess water (Doymaz and Ismail, 2011). The sample weight was recorded and the rehydration ratio was calculated according using the equation,

$$\text{Rehydration ratio} = \frac{\text{Weight of the rehydrated sample (g)}}{\text{Weight of dried sample (g)}} \quad \ldots 3.14$$

3.7.7 Water Activity (a_w)

The water activity of dried slices was measured by using Aqua lab water activity meter. The sample under test was kept in sample cup in which 2 g of ground sample was taken in sample cup which was provided with water activity meter. The reading displayed on the water activity meter was taken as water activity of the ground jackfruit powder (Murphy *et al.*, 2003).

3.7.8 Crude Fibre

Two gram of the sample (W) was ground and boiled with 200 ml H_2SO_4 for 30 min. Then the sample was filtered through muslin cloth and washed with hot water

for two - three times to remove the acid (Pritty *et al.*, 2013). The residue obtained was boiled with 200 ml NaOH and filtered through muslin cloth again and washed with 25 ml of 1.25% H_2SO_4, 350 ml of water and 25 ml alcohol. The residue was transferred to ashing dish (weight of residue + ashing dish = W_1) and dried for two hour at 130 ± 2°C. Weight of the dish and the residue (W_2) was taken after cooling in the desiccators. The dish was further ignited for 30 min at 600 ± 15°C and weighed after cooling (W_3).

$$\text{Crude fibre content (\%)} = \frac{(W2-W1)-(W3-W1)}{W} \quad \ldots 3.15$$

Where,

W_1= weight of residue + ashing dish (g)

W_2= Weight of the dish and the residue (g)

W_3=Weight of the sample along with the crucible (g)

W=Weight of the ground sample (g)

3.7.9 Microbial Analysis

One gram of sample was weighed aseptically, blended for 15 min at room temperature and transferred aseptically to 9 ml of sterile distilled water to get 10^{-1} dilution and mixed well. From 10^{-1} dilution, one ml of aliquot was transferred to another test tube containing 9 ml sterile distilled water to get 10^{-2} dilution. Then this procedure was repeated upto 10^{-4} dilution. One ml of aliquot from different dilution was transferred to sterile Petri plates for the enumeration of bacteria and triplicates were taken. Approximately 15-20 ml of molten and cooled growth media (nutrient agar for bacteria) at temperature (45-50°C) were poured and the Petri plates were rotated clockwise and anticlockwise directions on the flat surface to have a uniform distribution of colonies. After solidification of agar, the plates were inverted and

incubated at room temperature for one day for bacterial growth. Total plate counts (TPC) were determined on plate count agar pour plates and enumerated after an incubation period of 24h at 30°C. The colonies were counted after the incubation period and the number of colony forming unit (cfu) per ml of sample was calculated by applying the following formula:

Number of colony forming units per ml of the sample

$$\text{No. of cfu/ml} = \frac{\text{Mean number of cfu} \times \text{dilution factor}}{\text{Vol of the sample}} \quad \ldots 3.16$$

3.7.10 Texture Analyser

Textural properties of fresh and dried jackfruit slices were studied using a texture analyser (TA.XT texture analyser, Stable micro systems Ltd. UK). Texture analyzer gave a three - dimensional product analysis by measuring distance, force and time. Force was measured against set distance and distance was measured to achieve set of forces. Cylindrical probe with 5 mm diameter compressed the sample which was kept on the base of the instrument.

The probe carrier contains a sensitive cell. The load cell has mechanical overload and under load protection and an electronic monitoring system that stops the motor drive when an overload condition was detected. Distance and speed control was achieved using a step motor attached to a fine lead screw that winds the probe carrier up and down.

The dried jackfruit slices were compressed using a cylindrical probe under a measure of force 2.5 kg in compression mode with a test speed of 1 mm/s under double compression mode. Three replications of each combination were taken for analysis. During the testing, the samples were held manually against the base plate and different tests were conducted according to TA settings. The firmness or hardness

(peak force in N), and toughness (area under the curve in N.sec) were determined from the force deformation curve (Goncalves *et al.,* 2010).

Texture Analyser Settings

Mode : Measure force in compression
Option : Return to start
Pre test speed : 0.5 mm/s
Test speed : 1 mm/s
Post test speed : 10 mm/s
Strain : 65%
Trigger type : Auto 303
Tare type : Auto
Data acquisition rate : 400 pps

3.7.11 Sensory Analysis

The quality of the chips mainly crispiness depends on frying temperature and time. Dried and stored chips fried in edible oil. The judges scored with respect to colour and appearance, taste, flavour, texture and overall acceptability Amerine *et al.* (1965) on a nine point hedonic scale shown in the (APPENDIX F).

3.8 SHELF LIFE STUDIES

The dried jackfruit slices were stored in LDPE 100 µm bags at ambient conditions. The quality attributes like moisture content, TSS, vitamin C, water activity, pH, texture, colour and microbial analyses were examined for dried jackfruit slices at one month interval for about ten months.

3.9 STATISTICAL ANALYSIS

Statistical analyses were carried out to study the effect of different parameters on all the dependent variables. Analysis of variance (ANOVA) was conducted with Factorial Completely Randomised Design (FCRD) for optimisation of different parameters involved in this study. The experimental design was done with the aid of the Design-Expert software version 7.0.0 (Statease Inc., Minneapolis, USA).

3.10 ENERGY CONSUMPTION FOR DEVELOPED MACHINE

The machine operation cost depends upon the energy consumption during the operations. Hence it is necessary to determine the total energy requirement for operating the machine. It was determined by using three phase AC static watt hour meter during steam production per hour and drying the samples at different temperature at various thicknesses.

3.11 COMPARISON OF DEVELOPED BLANCHER CUM DRYER FOR EXISTING MACHINE

The performance of developed machine was compared with the existing machines in terms of capacity, power consumption, time consumption, cost of labour, cost of fabrication and quality of dried product.

3.12 COST ECONOMICS

Based on the cost of fabrication, variable costs, the total operational cost was calculated for developed blancher cum dryer and cabinet tray dryer. The estimation cost of processing the jackfruit slices was carried out using standard procedure.

CHAPTER IV
RESULTS AND DISCUSSION

This chapter deals with the results and discussion on the development, performance evaluation and optimisation of process parameters in blanching cum drying for matured jackfruit slices. Quality aspects and storage of the dried jackfruit slices are enumerated and discussed in this chapter.

4.1 TESTING OF DEVELOPED BLANCHER CUM DRYER

Blancher cum dryer was fabricated with a volume of 2.052 m^3 using SS 304 sheet and performance was evaluated in terms of loading capacity (kg/tray), time and energy required for steam generation, blanching and drying processes. Steaming chamber was fabricated with a capacity of 60 *l* using SS 304 sheet. The water level was maintained above the coils to ensure the performance of the blancher cum dryer. Heaters were operated at two efficiencies with an energy consumption of 6 kW and 10 kW. At higher efficiency, 30 min time duration was taken to attain the blanching temperature. The experiments were conducted at three different drying temperatures *i.e.*, 60, 65 and 70°C, with air velocity of 2.8-3.2 m/s. The quality of dehydrated slices was evaluated after drying.

4.1.1 Capacity of the Dryer

The loading capacities of the developed blancher cum dryer and existing cabinet dryer were found out by placing the pretreated jackfruit slices in all the twelve trays, which were arranged in the frame assembly. Loading capacity of each tray at three different loads *ie.*, L1, L2 and L3 were found to be 3.8, 4.8 and 5.8 kg/m^2 in the developed blancher cum dryer, where as in existing cabinet tray dryer were 3.2, 4.2 and 5 kg/m^2 respectively. The full load capacities of the dryers at all the three loads were 18, 23 and 28 kg in the developed dryer and 12, 15.5 and 18 kg in the cabinet dryer, respectively.

4.2 PHYSICO - CHEMICAL CHARACTERISTICS OF MATURED JACKFRUIT SLICES

The physical and chemical characteristics of fresh sliced matured jackfruit of *'Varikka'* variety was estimated as per the standard procedures and are presented in Table 4.1. The average values of the chemical components *viz.,* pH, total soluble solids, water activity, vitamin C and crude fibre content were estimated to be 5.67, 6.5°B, 0.964, 5.5 mg/100 g, and 10.2% respectively. The texture qualities firmness and toughness were found to be 11.81 ± 0.54 N and 4.24 ± 0.19 N.sec respectively. The colour values of the matured jackfruit were found out by Hunter lab colourimeter and 'L*', 'a*', and 'b*'were 70.55 ± 0.3, 1.34 ± 0.4 and 26.24 ± 0.5, respectively.

Table 4.1 Physico-chemical characteristics of sliced matured jackfruit

Chemical characteristics		**Mean ± SD***
Moisture content (%)		76.66
Water activity		0.964 ± 0.03
TSS (°B)		6.5 ± 0.28
pH		5.67
Vitamin C (mg/100 g)		5.5 ± 0.19
Crude fibre content (%)		10.2 ± 0.46
Physical characteristics		
Texture	Firmness (N)	11.81 ± 0.54
	Toughness (N.sec)	4.24 ± 0.19
Colour values	L*	70.55 ± 0.3
	a*	1.34 ± 0.4
	b*	26.24 ± 0.5

*SD: Standard Deviation

4.3 STANDARDISATION OF BLANCHING TREATMENT

The optimisation of pretreatments was carried out in blancher cum dryer for matured jackfruit slices with uniform thickness of about 7.62 ± 0.33 mm. The samples were pretreated with steam blanching and steam blanching along with preservatives such as citric acid (0.1, 0.2 and 0.3%), potassium metabisulphate (0.1%) and turmeric powder (0.1, 0.3, and 0.5%) at different blanching time (6, 7, 8 and 9 min). All the pretreatments with various concentrations were as follows C1 (control), C2, C3, C4, C5, C6, C7, C8, C9 and C10. Based on the enzyme inactivation blanching time was optimised and best preservatives were selected. The effect of pretreatments on colour (*L**, *a** and *b**) and texture (firmness and toughness) were evaluated.

4.3.1 Optimisation of Blanching Time and Treatment

The steam blanching was standardised based on the result of peroxide and catalase enzyme inactivation. These enzymes play a crucial role in the shelf life of products, and also quality attributes like texture and colour. Inactivation of enzymes was mainly dependent on temperature and preservatives in the blanching medium and mass of slices (Negi and Roy, 2000).

Based on the preliminary studies, matured slices were steam blanched for different duration of time (6, 7, 8 and 9 min), to observe the negative result in both hydrogen peroxide and catalase test. In the present study each pretreatment was replicated thrice to verify the presence of enzymes at 80ºC blanching temperature. The enzyme presence was noticed upto 6 min of blanching, but enzyme was inactivated in the further blanching timings *i.e.,* at 7, 8 and 9 min. Finally it was concluded that, at least 7 min of blanching was necessary for complete inactivation of enzymes. The status of enzyme inactivation for each treatment is listed in Table 4.2. When compared to all the pretreatments, complete enzyme inactivation occurred at C7 (Steam blanching + 0.2% citric acid + 0.1% KMS + 0.5% Turmeric powder)

treatment. Hence, C7 pretreatment was considered as best preservative. Among the preservatives, citric acid helps to reduce the drying time, browning reaction, heat-treatment requirements by lowering pH, inactivates undesirable enzymes and supplies flavour (FAO, 2004). Sodium metabisulphate (KMS) as a preservative helps in improving the colour and texture (Prajapati *et al.,* 2009), prevents the enzymatic browning of fruits in addition it increase the permeability of water (Doymaz, 2004) and turmeric powder helps in extending the shelf life, used as antimicrobial agent and maintain the colour of jackfruit. In the present investigation 7 min, 8 min and 9 min of blanching time required for thin, medium and thick loads respectively. As increasing the loading capacity higher blanching time may be required. Similar results were reported by Pan *et al.* (2005) for pear cubes. The samples were cooled immediately after blanching for about 3 min to avoid the overheating of samples.

Table 4.2 Status of enzyme inactivation

Blanching time (min)	Treatments									
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
6	+	+	+	+	+	+	+	+	+	+
7	+	+	+	+	+	+	-	+	+	+
8	-	-	-	-	-	-	-	-	-	-
9	-	-	-	-	-	-	-	-	-	-

Thus the experiment was further carried out with standardised blanching time starting from 7 min and extending up to 9 min for different loads, each blanching time was carried out at one min time interval. All the blanching times were replicated thrice and the best pretreatment was standardised.

4.3.2 Effect of Blanching Time and Pretreatment on Textural Attributes

The firmness and toughness of fresh matured jackfruit slices were 11.81 ± 0.54 N and 4.24 ± 0.19 N.sec respectively, and measured by compression tests in texture analyser. ANOVA (Appendix A1 and A2) shows that blanching time and preservatives have significant ($p \leq 0.0001$) effect on the firmness and toughness of the blanched samples. From the Table 4.3, it could be observed that as increasing in the blanching time, both firmness and toughness were decreased. Similar observation was reported by Pritty and Sudheer (2012) for tender jackfruit.

Table 4.3 Effect of blanching time and preservatives on texture of matured jackfruit slices

Sl. No.	Treatments	Blanching time					
		7 min		8 min		9 min	
		Firmness (N)	Toughness (N.sec)	Firmness (N)	Toughness (N.sec)	Firmness (N)	Toughness (N.sec)
1	C1(control)	11.81±0.5	4.24±0.19	11.81±0.31	4.24±0.11	11.81±0.51	4.24±0.18
2	C2	6.56±0.23	1.50±0.05	6.46±0.28	1.52±0.06	6.32±0.21	1.8±0.06
3	C3	5.24±0.13	1.20±0.03	4.7±0.21	1.88±0.08	4.68±0.21	0.99±0.04
4	C4	4.65±0.20	1.88±0.08	4.63±0.21	0.45±0.02	4.07±0.14	1.77±0.09
5	C5	6.12±0.21	0.96±0.03	5.2±0.18	1.65±0.05	4.6±0.12	0.95±0.02
6	C6	5.28±0.24	0.43±0.01	4.12±0.10	0.96±0.02	4.02±0.14	0.50±0.01
7	C7	4.56±0.16	0.72±0.02	4.4±0.19	0.42±0.01	4.25±0.15	0.95±0.03
8	C8	6.32±0.16	0.50±0.01	5.83±0.20	0.43±0.01	5.83±0.15	1.09±0.02
9	C9	6.21±0.22	1.11±0.04	4.25±0.19	1.69±0.07	3.64±0.15	0.71±0.03
10	C10	5.93±0.21	0.75±0.02	4.07±0.14	1.92±0.06	4.02±0.18	1.75±0.08

Lee *et al.* (1979) observed that blanching affects the firmness of the tissue because of inactivation of pectin methylesterase. When the citric acid concentration increased from 0.1 to 0.3% the firmness was decreased as shown in Fig. 4.1. Master *et*

al. (2000) also observed that firmness of treated samples decreased significantly. The toughness of treated sample was low compared to control sample, as observed by Praveena and Sudheer (2015). As increase citric acid concentration toughness was increased as presented in Fig. 4.2.

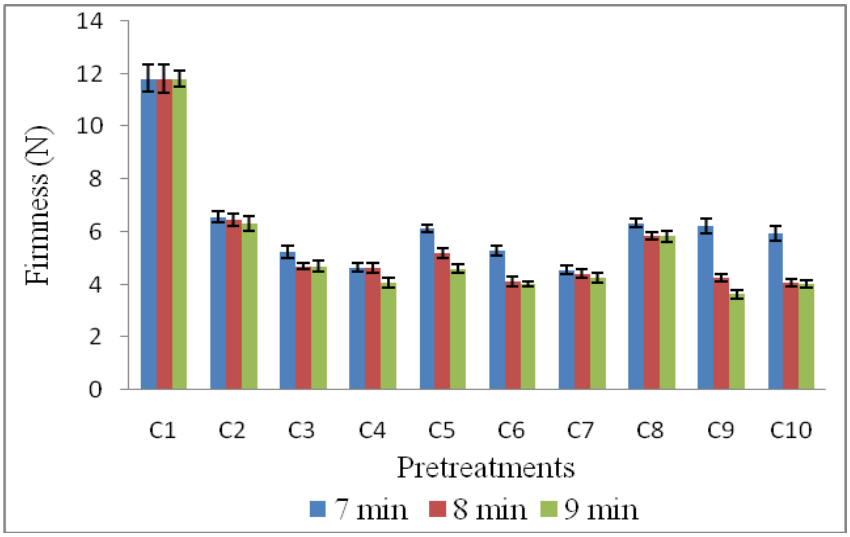


Figure 4.1 Effect of pre - treatments on firmness

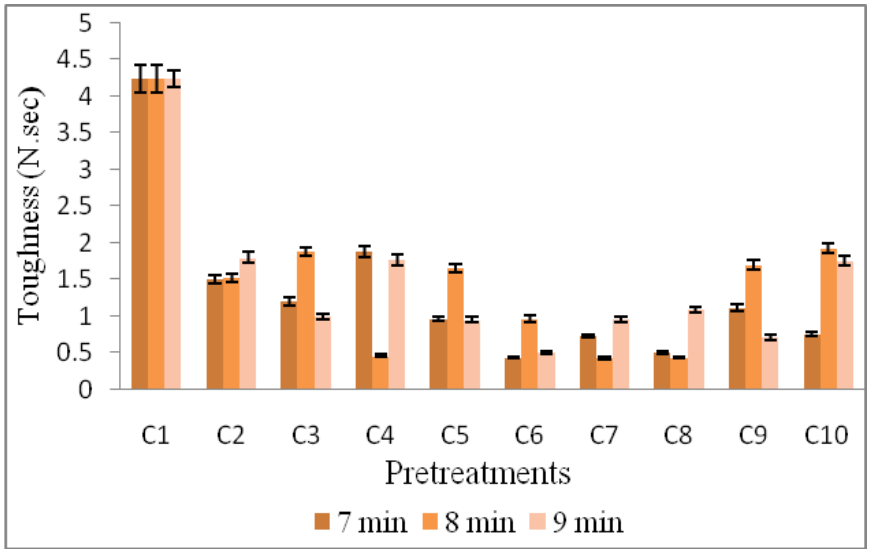


Figure 4.2 Effect of pre - treatments on toughness

Compared to other treatments, firmness and toughness was slightly lower at C7 treatment and enzyme inactivation occurred at that treatment, hence it was selected as best combination.

4.3.3 Effect of Blanching Time and Pretreatments on Colour Attributes

The colour values were obtained using Hunter lab colourimeter by analysing the L*, a* and b* values as shown in Table 4.4. The average colour values of the reference raw samples of 'L*', 'a*' and 'b*' are 70.55, 1.34 and 26.24, respectively. The statistical analysis of ANOVA (Appendix A3) revealed that the blanching time and preservatives had no significant effect on the lightness. This could be due to the disintegration of chlorophyll pigment during blanching process. The effect of pretreatments on lightness L* at different blanching time is shown in Fig. 4.3. Lightness values for blanched sample ranged from 71.09 to 73.26. As blanching time increased, lightness value shows slight increasing trend for all the preservatives. A similar colour changes was observed by Llano *et al.* (2003) for kiwifruit during steam blanching.

Blanching time and preservatives had significant ($p<0.0001$) effect on a* value as shown statistically in ANOVA (Appendix A4). Fresh samples had less a* value compared to pretreated samples. As blanching time increased from 7 to 9 min redness value was decreased gradually. Similar changes were observed by Ndiaye *et al.* (2009) for mango slices. The redness (a*) value was decreased irrespective of the blanching pretreatments as shown in Fig. 4.4 and value ranged in between 1.69 to 2.8.

From the Fig. 4.5, it was clear that, as the blanching time increased from 7 min to 9 min, yellowness (b*) was increased, due to pigmentation by turmeric powder. The statistical analysis showed that preservatives and processing time had significant ($p<0.0001$) effect on the L* value (Appendix A5). There was not much

variation in yellowness observed in between C7 and C10 treatments but the enzyme inactivation was occurred in C7 treatment, so it was considered as best pretreatment.

Table 4.4 Effect of pretreatments and blanching time on colour attributes

Sl. No.	Treatments	L*			a*			b*		
		7 min	8 min	9 min	7 min	8 min	9 min	7 min	8 min	9 min
1	C1	70.55	70.55	70.55	1.34	1.34	1.3	26.24	26.24	26.24
2	C2	71.09	71.59	72.12	2.8	2.75	2.71	38.71	38.82	38.72
3	C3	71.17	71.67	72.36	2.58	2.53	2.49	39.13	39.26	39.93
4	C4	72.59	71.45	72.49	2.23	2.17	2.1	40.82	41.1	41.89
5	C5	71.65	72.1	72.7	2.69	2.51	2.46	36.82	38.36	39.1
6	C6	71.89	72.35	72.83	2.12	2.49	2.35	38.93	39.91	40.32
7	C7	72.32	72.51	73.01	2.35	2.25	2.2	41.2	41.86	42.3
8	C8	71.12	72.36	72.76	2.4	2.23	2.18	36.91	39.12	39.25
9	C9	72.79	72.67	73.1	2.07	1.75	1.7	39.73	40.57	41.78
10	C10	72.96	72.91	73.26	1.88	1.69	1.62	42.09	42.89	43.19

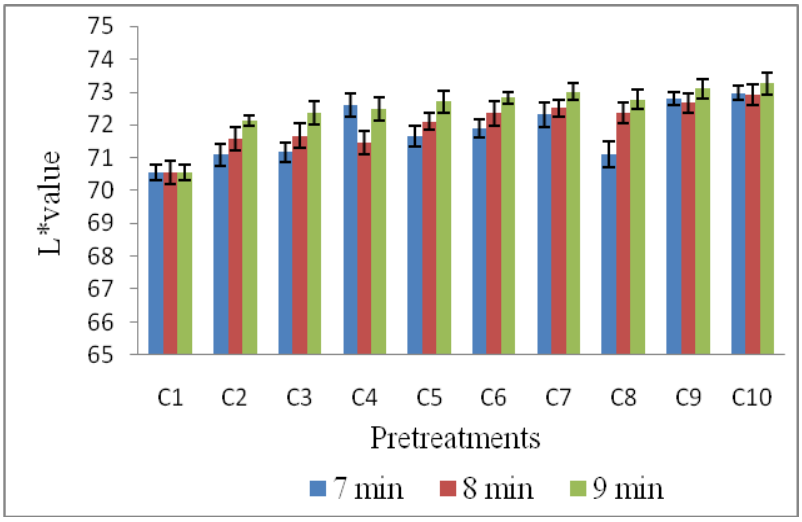


Figure 4.3 Effect of pre - treatments and blanching time on lightness value (L*)

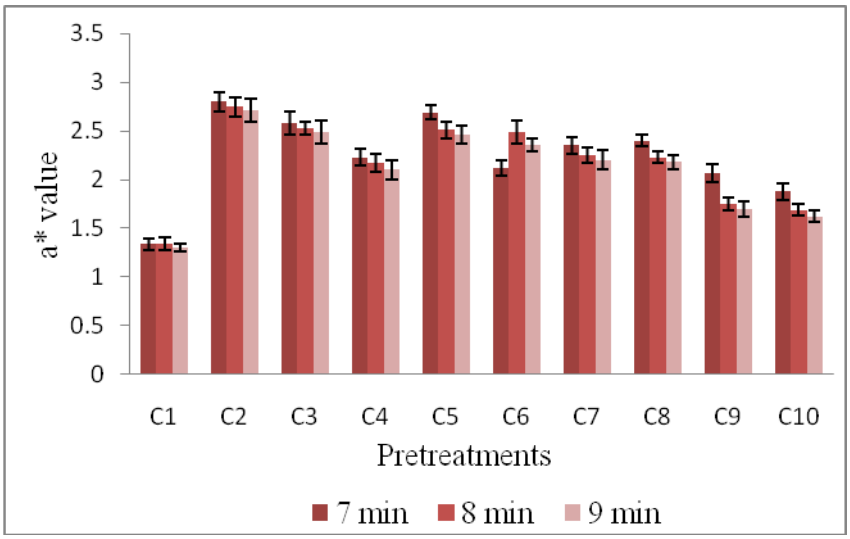


Figure 4.4 Effect of pre - treatments and blanching time on a* value

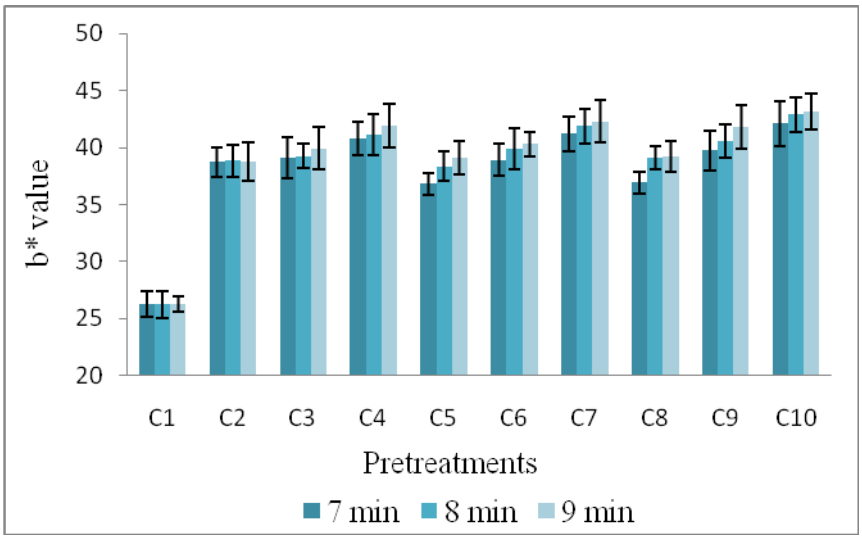


Figure 4.5 Effect of pre - treatments and blanching time on b* value

Total colour difference (ΔE) was increased with increase in the blanching time. A significant ($p<0.0001$) variation was observed with preservatives and blanching time (Appendix A6). Total colour difference and *Chroma* values with respect to blanching time and preservatives are shown in the Fig. 4.6 and 4.7. In the present study minimum colour change was observed at C2 treatment and maximum

was observed at C7 and C10 treatment, but the enzymatic presence was positive at C10 treatment. When compared to C10 treatment, minimum total colour change was observed at C7 treatment and peroxidase and catalase enzymatic presence shows negative, hence C7 was considered as the best treatment.

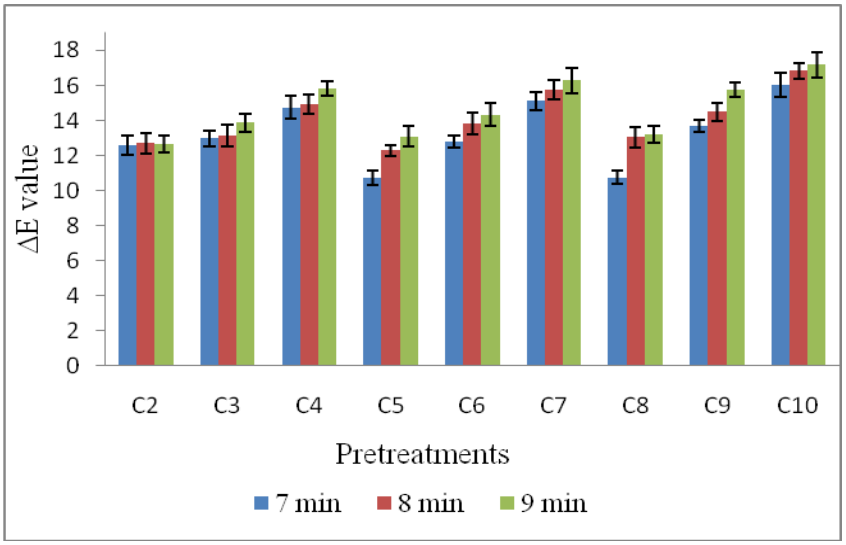


Figure 4.6 Effect of pre - treatments and blanching time on total colour change (*ΔE*)

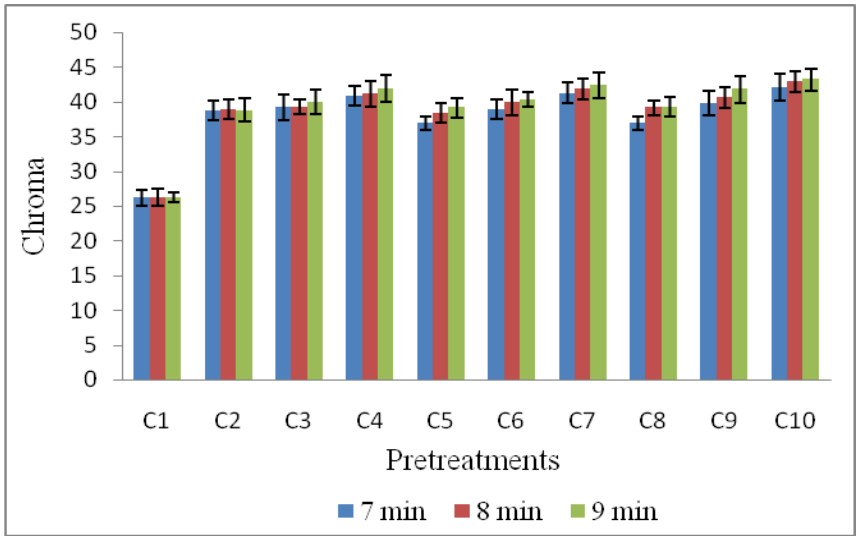


Figure 4.7 Effect of pre - treatments and blanching time on *Chroma*

The *Chroma* value for fresh jackfruit sample was 26.27 ± 1.14. Higher reduction in *Chroma* value was observed in control samples when compared to the pretreated samples. Similar change was observed by Saxena *et al.* (2008) for jackfruit. Blanching time and preservatives had significant ($p<0.0001$) variation with *Chroma* values. In the present study more *Chroma* values observed at C4 followed by C7 and C10 treatements, but based on peroxidase and catalase enzyme inactivation C7 was taken as the best treatment. After observing all colour parameters *L**, *a**, *b**, *ΔE* and *Chroma*, C7 treatment was considered as the best pretreatment.

4.4 EFFECT OF DRYING TEMPERATURE AND LOADING RATE ON MOISTURE CONTENT OF MATURED JACKFRUIT SLICES DURING DRYING

The matured jackfruit slices of 7.62 ± 0.33 mm thickness spread on perforated trays in three different loads. After standardising the pretreatments drying process was carried out in blancher cum dryer with an air velocity of 2.8-3.2 m/s. Drying experiments were performed at three selected temperatures, *i.e.*, 60, 65 and 70°C for different loads as provided in Table 4.5. The results obtained shows that drying time decreased greatly when drying temperature increased from 60-70°C, due to increased heat transfer. Similar results were also reported by earlier researcher Doymaz, (2010) for Amasya red apples. Drying times for different loading rates have increased with increasing in the loading rates, which ranges between 300 to 480 min. Compared to treated and blanched samples, the drying time of control samples was higher. Drying was performed until the final moisture content reached below 10% (w.b.). The dehydrated samples at three different temperatures and loading are presented in the Plate. 4.1.

Plate 4.1 Dehydrated jackfruit slices at different temperatures and loading

In case of cabinet tray dryer drying time required for pretreated sample at L3 load at three temperatures *ie.*, 60, 65 and 70°C were 420, 390 and 330 min, respectively. The samples were drawn in every half an hour interval for the estimation of final moisture content of the samples using a method as described in Chapter 3 section 3.7.1. The moisture content, drying rate and moisture ratio of jackfruit slices dried under blancher cum dryer at selected temperatures *ie.*, 60, 65 and 70°C are presented in the Tables 4.6, 4.7 and 4.8, respectively.

Table 4.5 Drying experiments with different temperatures and loading

Sl. No.	Combinations	Drying temperature (°C)	Blancher cum dryer	
			Loading rate (kg)	drying time (min)
1	Control	60	18	480
2	L1T1	60	18	420
3	L1T2	65	18	380
4	L1T3	70	18	300
5	L2T1	60	23	445
6	L2T2	65	23	400
7	L2T3	70	23	330
8	L3T1	60	28	470
9	L3T2	65	28	430
10	L3T3	70	28	360

As observed from the Tables, in case of L2 loading (23 kg) at 60 ± 2°C drying temperature to decrease the moisture content from 317.53% (d.b.) to 7.94% (d.b.) for pretreated matured jackfruit slices in developed blancher cum dryer seven hours of drying time was required. In case of 65 ± 2°C drying temperature six and half hours was required to decrease the moisture content from 351.26% (d.b.) to 7.61% (d.b.),

whereas at 70 ± 2°C drying temperature, five hours was required to decrease the moisture content from 328.44% (d.b.) to 7.15% (d.b.).

Table 4.6 Moisture content, drying rate and moisture ratio of jackfruit samples at 60°C

Sl. No.	Drying time (min)	Moisture content % (d.b.)	Drying rate (Moisture evaporated/min/100 gm of dry matter)	Moisture ratio
1	0	317.53	-	1
2	30	285.47	1.559332606	0.899
3	60	255.68	1.515151515	0.805
4	90	212.38	1.44238266	0.668
5	120	177.13	1.17469723	0.557
6	150	152.40	0.9278029	0.479
7	180	118.55	0.888819585	0.373
8	210	91.24	0.784864078	0.287
9	240	72.52	0.361245387	0.228
10	270	51.77	0.309267633	0.163
11	300	30.32	0.259888768	0.095
12	330	16.83	0.184521025	0.053
13	360	10.90	0.059774417	0.034
14	390	9.73	0.012994438	0.030
15	420	7.94	0.005197775	0.025

Table 4.7 Moisture content, drying rate and moisture ratio of jackfruit samples at 65°C

Sl. No.	Drying time (min)	Moisture content% (d.b.)	Drying rate (Moisture evaporated/min/100 gm of dry matter)	Moisture ratio
1	0	351.26	-	1
2	30	298.79	1.864904552	0.850
3	60	242.53	1.844346549	0.690
4	90	175.16	1.656387665	0.498
5	120	143.41	1.632892805	0.408
6	150	118.28	0.848751836	0.336
7	180	91.47	0.83113069	0.260
8	210	69.34	0.798825257	0.197
9	240	48.35	0.6989721	0.137
10	270	33.09	0.508076358	0.094
11	300	21.10	0.399412628	0.060
12	330	10.17	0.364170338	0.028
13	360	8.40	0.058737151	0.023
14	390	7.61	0.026431718	0.021

The effect of drying conditions on quality of dried products were studied in terms of moisture content, vitamin C, total soluble solids, texture, colour, pH, rehydration ratio and total plate count. The loss of quality during drying was statistically analysed using Analysis of variance (ANOVA) technique in Design expert software.

Table 4.8 Moisture content, drying rate and moisture ratio of jackfruit samples at 70°C with drying time

Sl. No.	Drying time (min)	Moisture content % (d.b.)	Drying rate (Moisture evaporated/min/100 gm of dry matter)	Moisture ratio
1	0	328.449	-	1
2	30	275.013	1.8942607	0.8373
3	60	219.119	1.7500707	0.6671
4	90	167.380	1.7246254	0.5096
5	120	125.819	1.3853548	0.3830
6	150	92.995	1.3740458	0.2831
7	180	45.921	1.2892282	0.1398
8	210	21.5787	0.8114221	0.0656
9	240	11.061	0.3505796	0.0336
10	270	9.449	0.0593723	0.0287
11	300	7.159786408	0.0367543	0.0217

4.5 EFFECT OF DIFFERENT DRYING TEMPERATURE ON DRYING TIME AND DRYING RATE OF MATURED JACKFRUIT SLICES

Drying behaviour of blanched samples were analysed in terms of drying rates and these were mainly dependent on temperature. Predictive models for drying behaviour were developed under different drying conditions. The drying rate was calculated as amount of moisture evaporated per min per unit dry matter as explained in Chapter 3 of Section 3.6.1. Fig. 4.8 shows the drying rate curve was plotted for drying rate against drying time at three temperatures 60, 65 and 70°C. It could be

observed that the higher the drying temperature the shorter drying times required for samples to reach the desired final moisture content. Similar findings were reported by the Idah *et al.* (2014) for tomato fruits.

The drying rate curve shows that constant rate period of drying was not observed in the dehydration of jackfruit slices. The entire drying process was occurred in the falling rate period due to internal mass transfer occurred by diffusion process. This shows that physical mechanism governing moisture movement in the sample was dominated by the diffusion of water vapor or bound water through the dry tissue to the drying air. This was in agreement with earlier studies reported by Sobukola *et al.* (2008); and Doymaz *et al.* (2010) for yam and Amasya red apples.

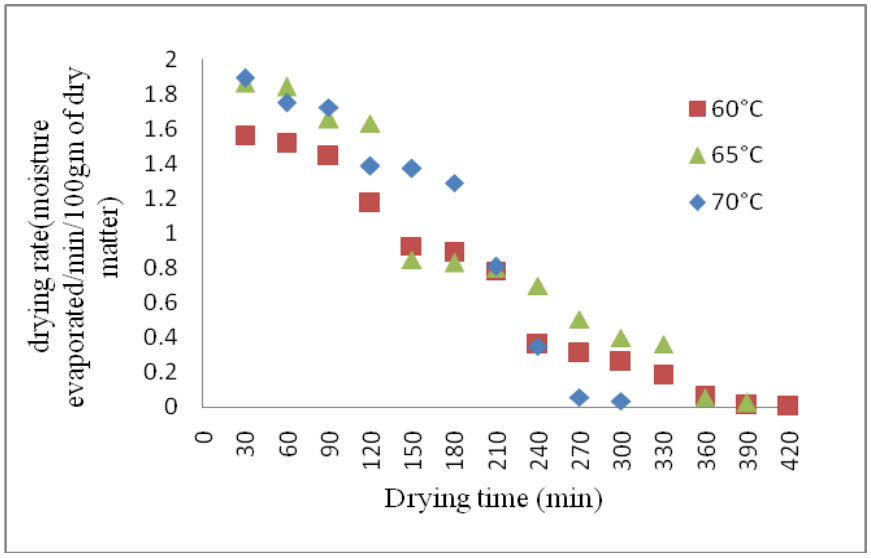


Figure 4.8 Drying rate curve for different drying temperatures with respect to drying time

4.6 MATHEMATICAL MODELING OF JACKFRUIT SLICES AT DIFFERENT DRYING TEMPERATURES

In order to determine the drying characteristics of jackfruit slices, drying was carried out in blancher cum dryer at three drying temperatures 60, 65 and 70°C. Four

different drying models namely, Newton, Page, Henderson and Pabis, and Logarithmic models were selected based on their ability to best fit the experimental data. The drying constants for selected models were evaluated by using a MATLAB R2013a Software and compared by means of the coefficient of determination (R^2).

The goodness of the fit was determined using estimated values of statistical parameters viz., reduced chi-square (χ^2), standard square error (*SSE*), coefficient of determination (R^2) and root mean square error (*RMSE*). For the best quality fit R^2 value should be high and, χ^2, SSE and RMSE values should be low. The constants of various drying models for different drying methods are shown in Table 4.9. The estimated values of statistical parameters of various models for different drying temperatures are presented in the Table 4.10.

Page model was described the best fit to experimental data with highest R^2 value of 0.998 and lower χ^2, SSE and RMSE values of 0.013475, 0.002529 and 0.01516, respectively at 60°C drying temperature. At 65°C drying temperature, R^2 value of 0.9973 and χ^2, SSE and RMSE values of 0.000304, 0.003651 and 0.01744, respectively, was observed. At 70°C drying temperature, R^2 value of 0.9951 and χ^2, SSE and RMSE values of 0.000601, 0.006017 and 0.02586, respectively. Similar findings were reported by Taib *et al.* (2013) with R^2 value of 0.997 for convective hot air dehydration of jackfruit bulbs at 60°C. The obtained result was also in line with the value of Giraldo-Zuniga *et al*. (2006), for jackfruit slices drying using a convective vertical tray drier and they reported Page model as the best model with highest R^2 value of 0.999.

The Page model successfully describes the relationship between moisture ratio and drying time than other models. Reduction in moisture content with respect to time for both actual and predicted values in drying curve is shown in Fig. 4.9. The moisture ratio reduced exponentially as the drying time increased reported by Doymaz (2007). At the entire drying temperature moisture ratio was reduced due to

increase in heat air supply and moisture migration as suggested by Demir *et al.* (2004). In this study moisture reduction was higher at higher temperature.

Table 4.9 Drying models constants

Sl. No.	Model	Constants	Drying temperature (°C)		
			60	65	70
1	Newton	k	0.008156	0.007707	0.008954
2	Page	k	0.0032	0.002884	0.001085
		n	1.188	1.195	1.433
3	Henderson and Pabis	a	1.043	1.047	1.07
		k	0.008495	0.008051	0.009525
4	Logarithmic	a	1.104	1.107	1.252
		c	0.006969	0.006569	0.006238
		k	-0.08363	-0.08504	-0.2209

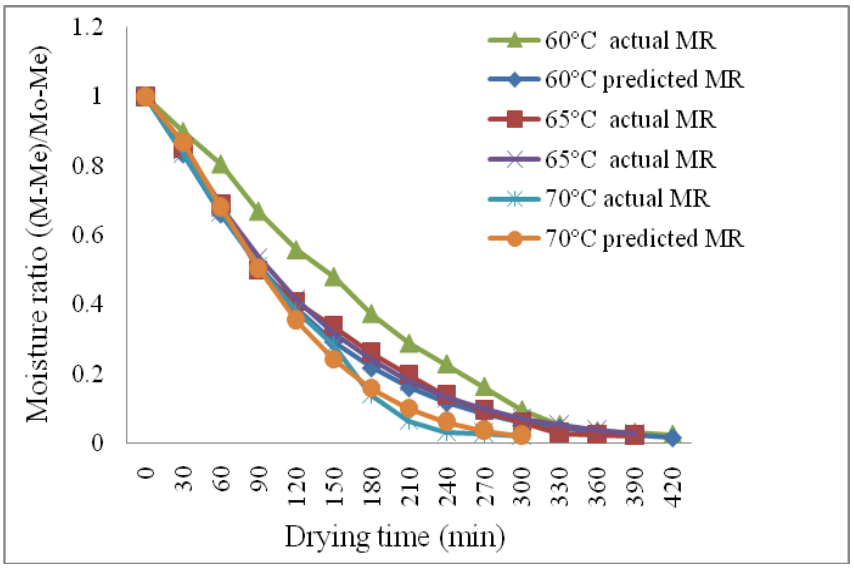


Figure 4.9 Experimental and Page model predicted moisture ratio for different drying temperatures

Table 4.10 Estimated values of statistical parameters of Newton, Page, Henderson and Pabis, and Logarithmic models used for three drying temperatures (60, 65 and 70°C)

Sl. No.	Parameter	Drying temperature (°C)	Models			
			Newton	Page	Henderson and Pabis	Logarithmic
1	SSE	60	0.01254	0.00252	0.009532	0.003064
		65	0.01524	0.00365	0.01159	0.00395
		70	0.04215	0.00601	0.009554	0.00303
2	R^2	60	0.99	0.998	0.9924	0.9976
		65	0.9887	0.9973	0.9914	0.9971
		70	0.9656	0.9951	0.9924	0.9976
3	Adj R^2	60	0.99	0.9978	0.9917	0.9971
		65	0.9887	0.9971	0.9907	0.9965
		70	0.9656	0.9945	0.9686	0.9889
4	RMSE	60	0.03232	0.01516	0.02944	0.0175
		65	0.03424	0.01744	0.03108	0.01895
		70	0.06492	0.02586	0.06202	0.03693
5	$\chi 2$	60	0.01405	0.01347	0.014676	0.014689
		65	0.00117	0.00030	0.000965	0.000359
		70	0.00421	0.00060	0.003459	0.00429

4.7 SHELF LIFE STUDIES OF DEHYDRATED JACKFRUIT SLICES

The jackfruit slices were dehydrated at various combinations *i.e.,* different loading and drying temperatures. The dried samples were stored in LDPE (100 µm) bags at ambient storage conditions for a period of ten months. The change in the quality of jackfruit slices was analised at every one month interval to standardise the

best combination. The quality of dehydrated jackfruit slices obtained in cabinet tray dryer was similar to that obtained in blancher cum dryer.

4.7.1 Effect of Storage Period on Moisture Content of Dehydrated Samples

The moisture content of dehydrated jackfruit slices exhibited increasing trend as the storage period increased from 0 to 10 months. The change in moisture content was depicted graphically in Fig. 4.10. At the end of storage period maximum increase in moisture content was noticed in L2T3 (11.26%) and minimum was recorded both L2T2 and L3T3 with 9% as presented in (Appendix C1). The maximum mean increase in moisture content was observed in L2T3 (8.92%) and minimum mean was recorded in L2T2 (7.10%) and L1T2 (7.26%). ANOVA (Appendix B1) showed that for all the combinations moisture content was significantly ($p<0.0001$) increased during the storage period. These observations were in accordance with the reports of Patil (2003) for jackfruit chips and Rahman *et al.* (2007) for coriander powder. The gain in moisture during storage might be due to absorption of moisture from surroundings due to low equilibrium moisture content and hygroscopic nature of dehydrated product (Ong *et al.*, 2012).

4.7.2 Effect of Storage Period on Water Activity of Dehydrated Samples

The variation in water activity (a_w) of dehydrated jackfruit slices during storage is graphically shown in Fig. 4.11. The statistical analysis in the (AppendixB2) showed that storage period had significant ($p<0.0001$) effect on the a_w of dehydrated samples. Data pertaining to the effect of drying temperature and loading on a_w of dehydrated jackfruit slices during storage at ambient temperature are presented in (Appendix C2). Water activity was decreased with increase in the drying temperature due to higher water evaporation rate which influence the a_w of the sample. Similar results were reported by Cano-Chauca *et al.* (2002), for drying kinetics of banana.

Maximum increase in a_w was observed in L1T1 combination with 0.598 and minimum water activity was observed in the L2T2 with 0.548. However, it was on par with the combinations of L1T2 and L2T1. Drying process reduced the a_w of a food by inhibiting the growth of micro-organisms. Most enzymatic reactions were slow at low a_w *ie.,* <0.6 and safe for consumption. Water activity of samples was increased irrespective of the temperature and loading rate. This increase in a_w of the samples may decrease browning rate by diluting the reactive components (Sloan *et al.,* 2016). Water activity of the jackfruit slices were in the safe range during storage period.

4.7.3 Effect of Storage Period on pH Value of Dehydrated Samples

The pH value of dehydrated jackfruit slices obtained for different combinations during storage period is shown in (Appendix C3). The graphical representation of pH data given in Fig.4.12 shows a decreasing trend towards the ten months storage period. The decrease in pH might be due to decline in the acidic compounds during storage (Sandhu *et al*., 1985) or due to corresponding increase in acidity (Antarkar, 1991).

ANOVA (Appendix B3) shows that storage period significantly ($P<0.0001$) affect the pH value. The highest pH content was recorded in L1T1 (5.53) combination while in untreated control sample, it was 5.05. The lowest pH value was noticed in L2T2 (4.75). These two combinations (L1T2 and L2T1) were on par with the L2T2 combination. The mean values of dehydrated jackfruit slices decreased from 6.509 to 5.073 during storage period.

Henriette *et al.* (2006) reported that pH is one of the important factors in the chemical composition of product. As the low pH and low a_w in the combination allows the product microbiologically stable without the need of chemical preservatives for longer duration.

4.7.4 Effect of Storage Period on Vitamin C content of Dehydrated Samples

The variation of vitamin C content of dehydrated jackfruit slices during storage period is graphically represented in the Fig 4.13. As the drying temperature decreased, the mean value of vitamin C content decreased significantly from 9.104 to 6.913 mg/100 g during storage period. This change might be due to thermal degradation, and oxidation of vitamin C occurred during drying and storage respectively, as reported by Kumar and Sagar, (2016) for dehydrated guava slices.

Form the APPENDIX (C4) it could be observed that as storage period increased to ten months, vitamin C retention was higher in L2T1 (8.15 mg/100 g) combination followed by L1T1 (8.1 mg/100 g) and L3T1 (7.31 mg/100 g) combinations. Higher mean retention of vitamin C was observed in L2T1 (9.45 mg/100 g) combination.

A significant reduction of vitamin C was noticed in L3T3 (5.78 mg/100 g) and L3T2 (5.87 mg/100 g) combinations during storage period. This decrease could be due to oxidative and non-oxidative changes as explained by Eskin (1979). This might also be due to light and temperature during storage Pritty *et al.* (2013). Such changes during storage might deteriorate the colour and lower the flavour and nutritive value of the product. ANOVA (APPENDIX B4) showed that the storage period had significant ($p<0.001$) effect on the vitamin C.

4.7.5 Effect of Storage Period on TSS of Dehydrated Samples

The results obtained for TSS were statistically analysed and listed in the Appendix (B5). At the end of ten months storage period, maximum TSS was found in L1T2 (14.47°B) and significantly higher than rest of treatment combinations. The minimum TSS was noticed in case of L3T1 (11.61°B) combination throughout the storage period irrespective to the stages of observation.

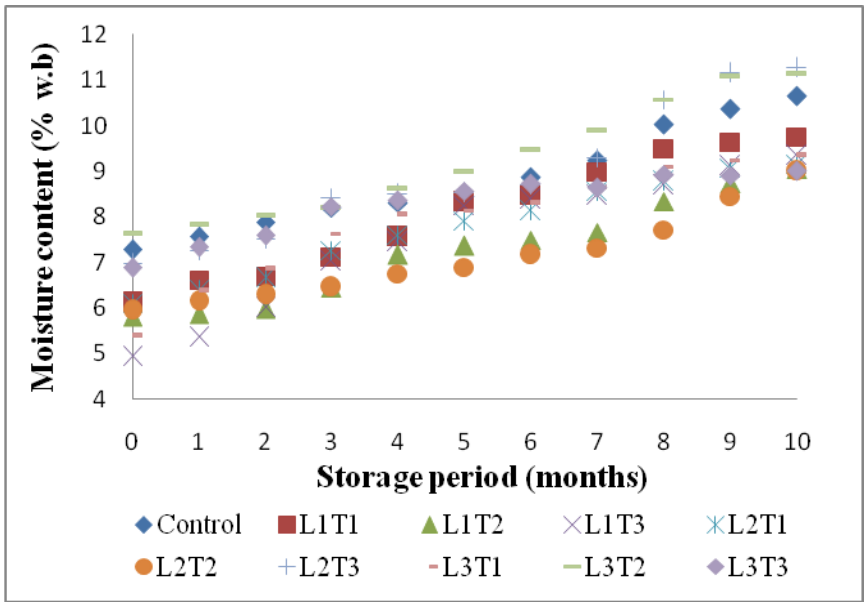


Figure 4.10 Effect of storage period on moisture content of dehydrated samples

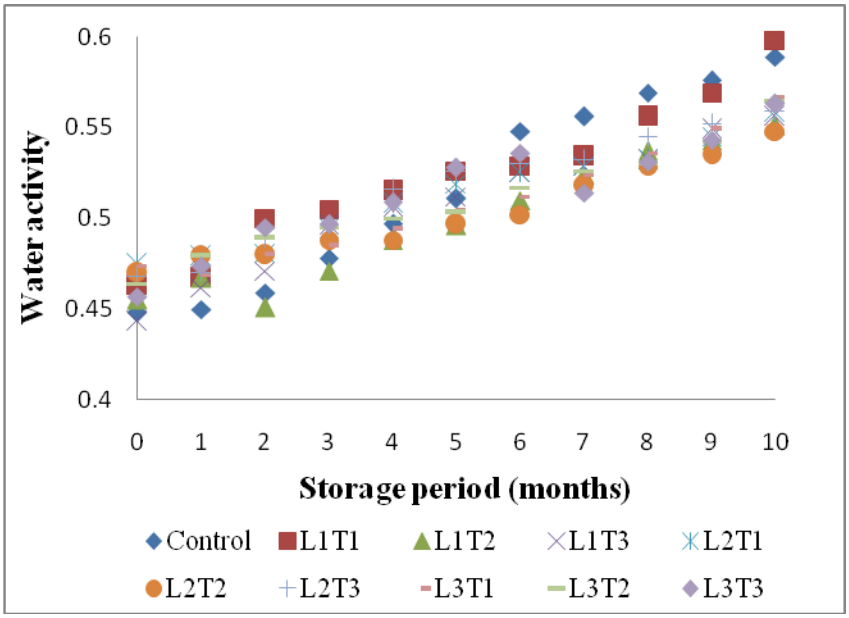


Figure 4.11 Effect of storage period on water activity of dehydrated samples

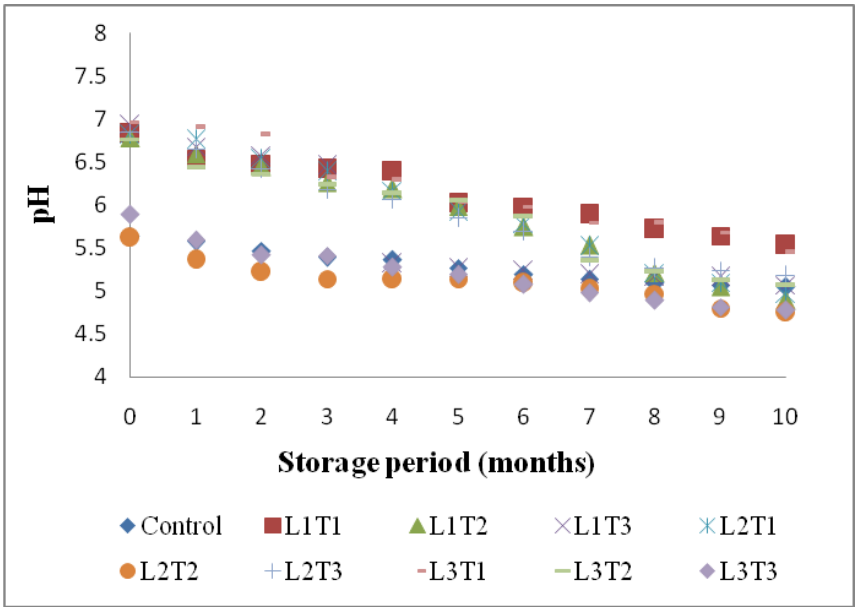


Figure 4.12 Effect of storage period on pH value of dehydrated samples

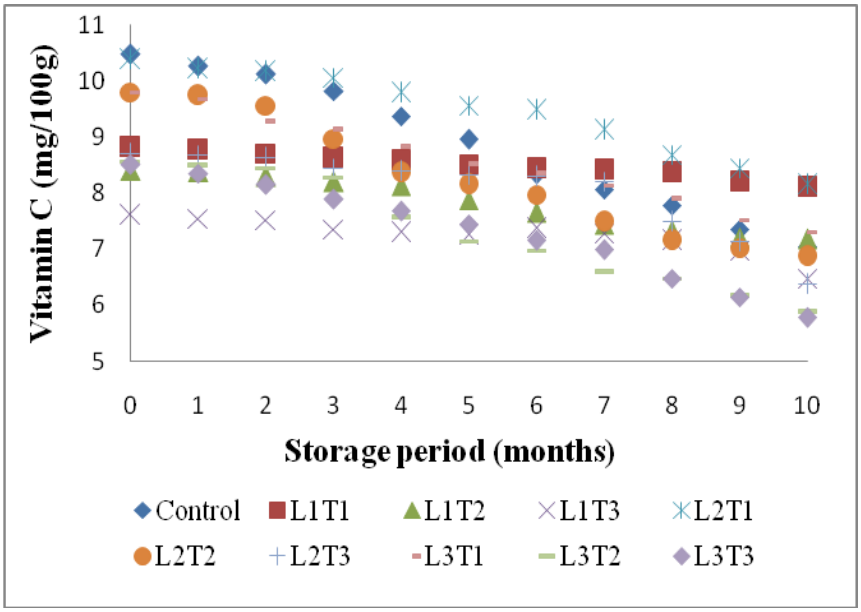


Figure 4.13 Effect of storage period on vitamin C content of dehydrated samples

Data recorded on effect of storage period on change of TSS content for dehydrated jackfruit slices at ambient temperature are presented in (Appendix C5). The TSS content of dehydrated slices increased with increase in storage period and is graphically shown in Fig 4.14.

These changes may be due to presence of acids conversion of non reducing sugars into sugars. The findings were in accordance with those reported by Sawant (2000); Patil (2003) for jackfruit slices and Pritty *et al.* (2014) for tender jackfruit. Highest mean TSS was noticed at ten months of storage period (13.85°B) while the lowest mean value recorded at initial stage of storage (9.611°B). Salunkha *et al*. (1974) noticed an increase in total soluble solids due to the degradation of polysaccharides during storage.

4.7.6 Effect of Storage Period on Firmness of Dehydrated Samples

The results obtained for firmness of dehydrated samples were statistically analysed and presented in the (Appendix B6). It was noticed that storage period had significant ($p<0.0001$) effect on the firmness of the samples. From the Fig. 4.15 it was clear that firmness of dehydrated jackfruit slices exhibited a decreasing trend during the storage period. The mean value of firmness was decreased from 44.677 to 36.944 N during the ten months of storage period.

The maximum increase in firmness was found in L1T3 (46.24 N) combination followed by L2T3 (41.51N) and L3T3 40.15N. It was noticed that increasing drying temperature enhanced the firmness of samples at the end of drying (AppendixC6). The results were in good agreement with the findings of Martynenko and Janaszek (2014) for apple slices.

The texture values were mainly dependent on the water activity of the product throughout the period of storage, as increase in the water activity and moisture content decreased the texture values. Similar observations had reported by Azeredo *et*

al. (2006) for mango leathers. This variation might be due to the permeation of moisture through the stored bags.

4.7.7 Effect of Storage Period on Rehydration Ratio of Dehydrated Samples

The effects of storage period had significant ($p<0.001$) effect on the rehydration ratio as presented in the ANOVA (Appendix B7). The Appendix (C7) revealed that compared to pretreated and dried sample the rehydration ratio of controlled sample was slightly higher. Similar findings were observed by Patro and Emmanuel (2014) for dehydrated kakrol. During the storage period, the rehydration ratio decreased with increasing moisture content. From the Fig. 4.16 it was observed that, at the end of storage period maximum rehydration ratio was observed in case of the L3T1 (1.012) and minimum was noticed in control sample (0.725) compared to all the combinations. The lower rehydration ratio was observed at higher drying temperatures (70°C) compared to lower drying temperatures.

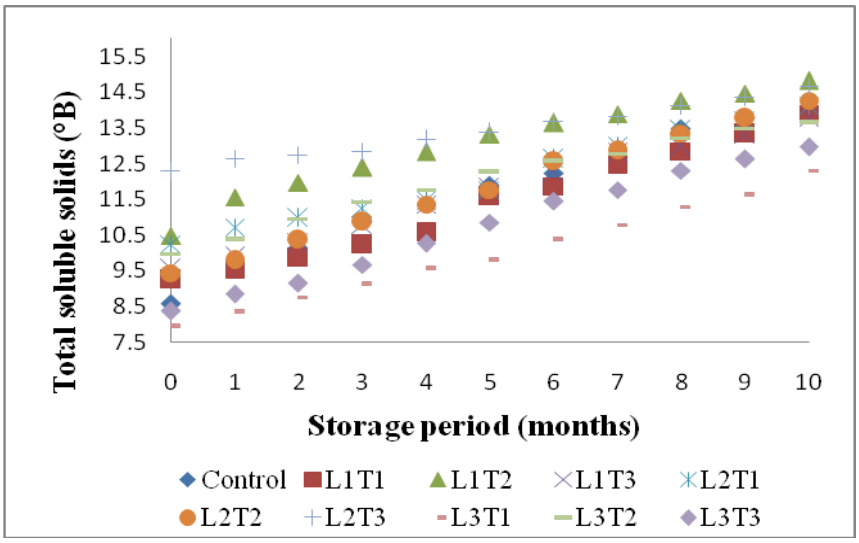


Figure 4.14 Effect of storage period on TSS of dehydrated samples

Similar observations were reported by Kaushal and Sharma (2016) for osmo convective dehydrated jackfruit flakes. This might be due to the decreased water

content at increased drying temperature and faster drying rate, which was responsible for more physico-chemical changes in the samples.

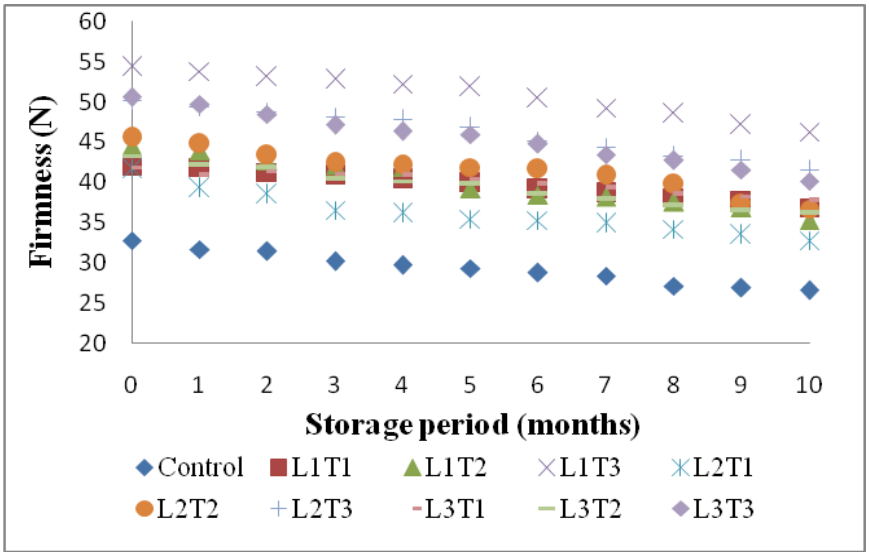


Figure 4.15 Effect of storage period on firmness of dehydrated sample

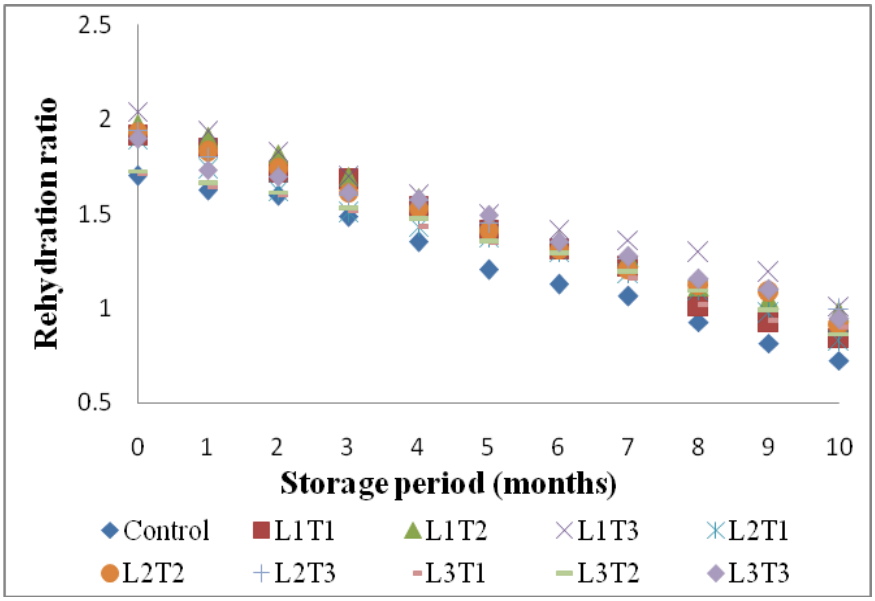


Figure 4.16 Effect of storage period on Rehydration ratio of dehydrated samples

4.7.8 Effect of Storage Period on Colour Values (L*, a*, b* and ΔE) of Dehydrated Samples

The total colour change (ΔE) of slices was used to assess the colour degradation kinetics and degree of browning during processing and storage.

4.7.8.1 Effect of storage period on L value of dehydrated samples*

The results of ANOVA analysis presented in the (Appendix B8) revealed that storage period had no significant effect on L* value during storage period. In some combinations L* value showed a decreasing trend, this could be due to the increased drying temperature. As the storage period increased the L* value slightly decreased and it was depicted graphically in the Fig 4.17. Initially higher L* value was noticed in case of L2T1 (84.62) combination for dehydrated jackfruit sample. At the end of storage maximum L* value was observed in L2T1 (81.56) followed by L2T2 (80.93) and L1T1 (80.62) treatment combinations. The maximum mean L* value was noticed in L2T1 (83.16) combination, and was on par with the L2T2 and L2T1 combinations as illustrated in the (Appendix C8). From the results it could be concluded that change in L* value was higher in L3T2 combination while it was lower at the L2T1 and L2T2 combinations. Pretreated samples maintain a significantly higher L* value compared to the control sample. Similar trend was observed by Saxena *et al.* (2008) for minimally processed jackfruit slices. It was also noticed that, a low drying temperature and increased drying period, decreased the L* value.

From the Fig 4.18, it was observed that greater a* values observed during the storage period. The effect of storage period had significant effect ($p<0.0001$) on a* value of dehydrated jackfruit samples shown in the ANOVA (Appendix B9). From the (Appendix C9) it was clear that the increased drying temperature had a significant variation in a* value during drying and storage. The L2T1 (1.54) combination obtained the lowest a* value at the end storage period, whereas higher a* value was

noticed in case of control sample (3.45) and L2T3 (2.39) combinations. The increased a* value during storage might be due to non enzymatic browning. A study published by Pua *et al.* (2008), reported a similar observation during storage for jackfruit powder.

The intensity of yellow colour (b* value) of dehydrated jackfruit slices exhibited a decreasing trend at the end of storage period (Fig 4.19). Maximum reduction of b* value was noticed in the control sample (21.34) followed by L3T1 and L1T3 were 26.45 and 27.39 respectively, from initial to final stage of storage. The higher yellowness was retained in case of the treated sample L1T2 (31.86) and L2T2 (30.43). The curcuminoids are natural phenols responsible for yellowness of turmeric powder. Samples which were exposed to higher temperature during drying, lost their yellowness. Statistical analysis carried out by using Completely Randamised Design (CRD) Appendix (B10) showed that the b* values were significantly affected during storage period for different combinations. From the Appendix (C10) it was found that maximum mean value was observed in L2T2 (34.52) followed by L1T2 (31.86) and minimum mean value was noticed in case of the controlled sample (23.71).

It could be observed that the total colour difference (ΔE) was increased significantly after ten months of storage and graphically presented in Fig.4.20. This clearly indicated the discolouration of jackfruit slices was due to browning reactions during storage. From the given (Appendix C11), it is evident that on comparing all the combinations minimum ΔE value was found in L1T2 (2.83) consequently followed by L2T1 (3.62) and L2T2 (3.67). Mean while maximum ΔE value was noticed in case of L3T3 (7.11) and L2T3 (6.94). The ΔE values in dehydrated jackfruit slices vary from 1.737 to 7.593 at the end of storage period. The ANOVA (Appendix B11) shows that the effects of storage period had significant effect ($p<0.0001$) on the total colour difference. The samples at high temperature gave relatively high overall total colour

change. In general L* and b* values decreased while increasing in a* value during the storage. This result was similar to the study of Pua *et al.* (2008) for jackfruit powder during storage.

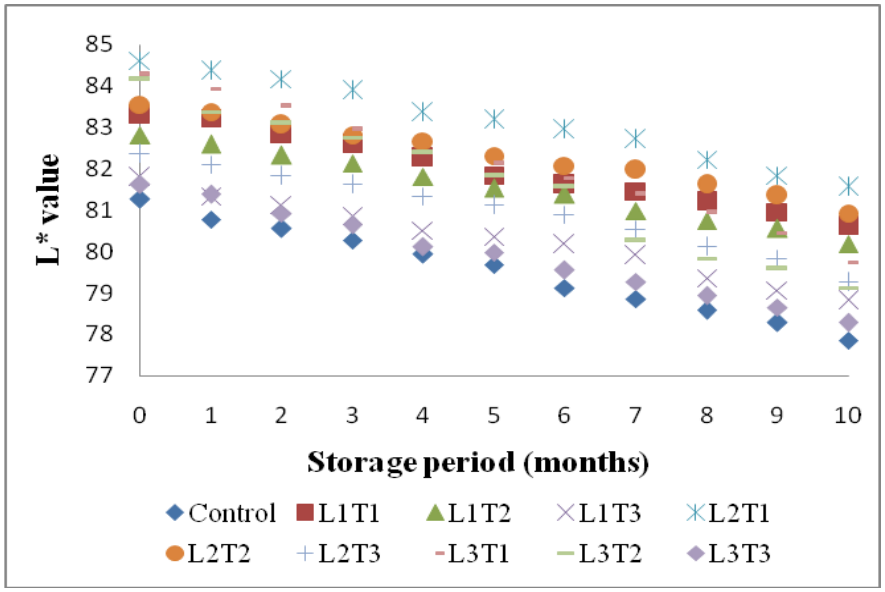


Figure 4.17 Effect of storage period on L* value of dehydrated samples

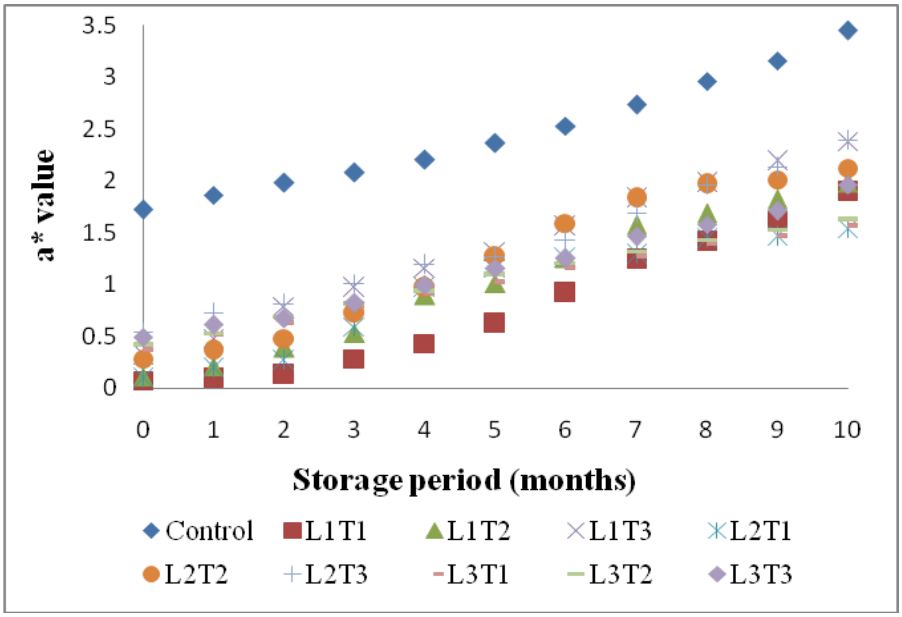


Figure 4.18 Effect of storage period on a* value of dehydrated samples

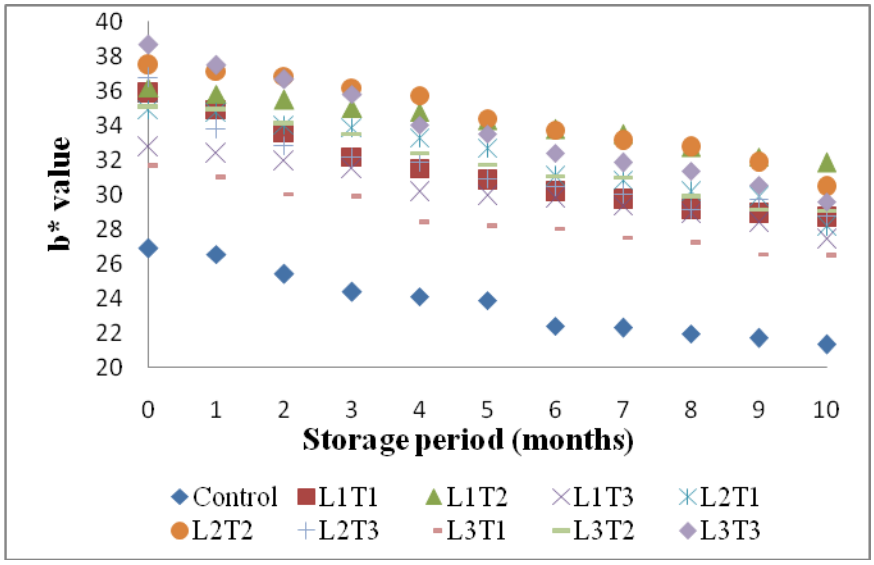


Figure 4.19 Effect of storage period on b* value of dehydrated samples

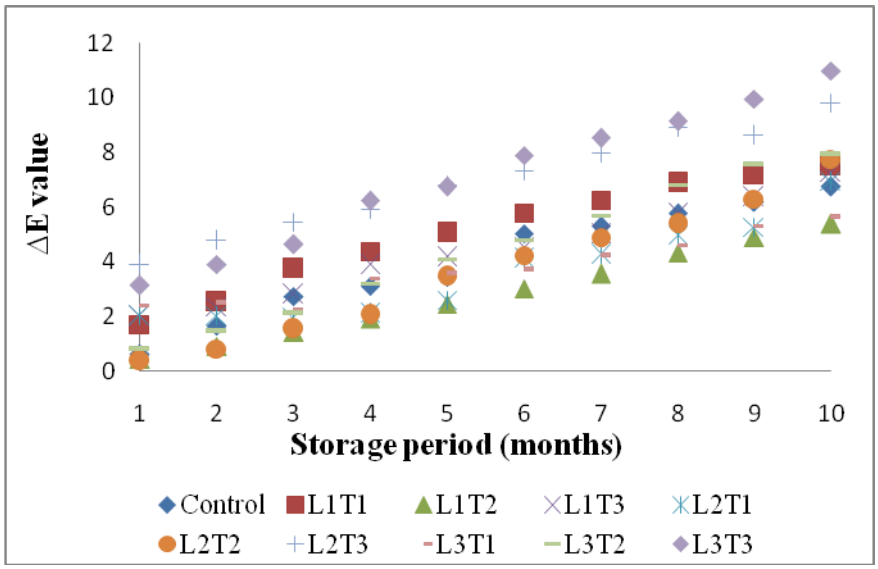


Figure 4.20 Effect of storage period on ΔE value of dehydrated samples

4.8 EFFECT OF STORAGE PERIOD ON MICROBIAL ANALYSIS OF DEHYDRATED JACKFRUIT SLICES

The microbial analysis was carried out for all the combinations during storage period at ambient conditions to estimate the bacterial growth. At the end of storage

period bacterial growth was maximum in case of the control samples (11.11 × 10^4 cfu/ml) followed by L2T3 (4.88 × 10^4 cfu/ml) and L3T2 (4.44× 10^4 cfu/ml). This could be due to the presence the higher moisture content and water activity Teja *et al.* (2016). The least microbial count was found in L2T1 (2.22 × 10^4 cfu/ml) followed by L2T2 (2.22 × 10^4 cfu/ml) and L1T2 (3.11 × 10^4 cfu/ml) combinations packed in LDPE (100 µm) bags was found safe upto ten months storage period. To keep the products safe for consumption, microbial load was within the permissible limit (not more than 50/ml) as prescribed by PFA, (2000). Microorganisms play a significant role in shelf life and storage stability of the food products. The obtained results of microbial analysis are listed in Table 4.11.

Table 4.11 Microbial analysis of dehydrated jackfruit slices during storage

Combinations	Bacterial growth (10^4cfu/ml)					
	Storage period (months)					
	0	**2**	**4**	**6**	**8**	**10**
Control	0	1.77	3.55	5.33	8.88	11.11
L1T1	0	0	1.33	1.77	2.66	3.11
L1T2	0	0	0.88	1.33	2.66	3.11
L1T3	0	0	1.33	1.33	2.22	2.66
L2T1	0	0	0	0.8	1.33	2.22
L2T2	0	0	0	1.33	1.77	2.22
L2T3	0	1.33	1.77	2.22	3.55	4.88
L3T1	0	0	1.33	1.77	2.66	3.55
L3T2	0	1.33	1.77	2.22	2.66	4.44
L3T3	0	0	1.33	1.77	2.22	3.11

4.9 SENSORY EVALUATION OF DEHYDRATED JACKFRUIT SLICES DURING STORAGE

The best judged and microbiologically safe samples were selected at the end of storage period and sensory qualities such as colour and appearance, taste, flavour, texture and overall acceptability were evaluated and results presented in (Appendix C13). The statistical analysis of various combinations had significant effect on the organoleptic scores of the dehydrated slices except flavour. The sensory evaluation carried out by a panel of 12 semi trained members using 9 point Hedonic scale. Among all combinations, L2T1 (7.77) ranked maximum mean score for overall acceptability irrespective of storage period followed by L2T2 (6.86). The minimum mean acceptability score was recorded in controlled sample and L1T2 combinations were 6.59 and 6.4, respectively.

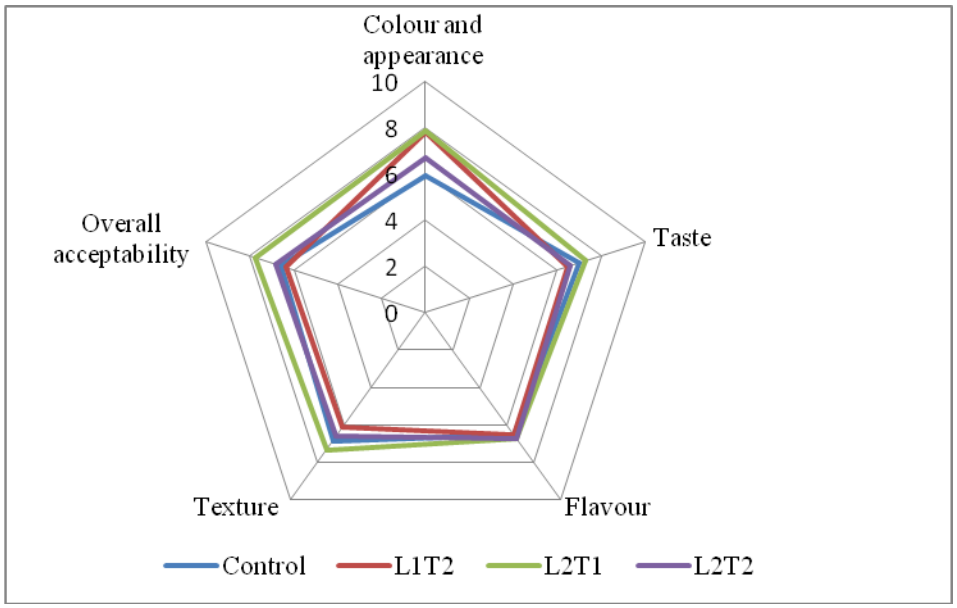


Figure 4.21 Sensory evaluation of dehydrated jackfruit slices during storage

4.10 STANDARDISATION OF DEHYDRATED SAMPLE

For assessing the best sample, experiments were conducted to develop a product which would have maximum sensory score, vitamin C, total soluble solids, colour and minimum moisture content, water activity, rehydration ratio and microbial load. Under these criteria L2T1 (loading capacity 23 kg at 60°C) combination was optimised and selected as best combination out of all the selected combinations during experiment. The optimised response was predicted by the Design-Expert 7.0.0 software.

4.11 COST ECONOMICS FOR DEVELOPED BLANCHER CUM DRYER AND CABINET TRAY DRYER

The cost economics for the developed blancher cum dryer was calculated by taking the cost of one unit electricity as Rs.7/kWh. Therefore the energy cost per hour in blancher cum dryer and cabinet tray dryer were Rs.45.02 and 79.80, respectively. The machines cost for blancher cum dryer and cabinet tray dryer were Rs.2,00,000 and 1,50,000 by considering all the material and fabrication costs. The dehydrated jackfruit slices were produced by taking all the aspects of fixed and variable costs involved in the investigation. The benefit cost ratios of the dehydrated jackfruit slices packed in LDPE (100 µm) using combo drier and cabinet tray dryer were 4.65:1 and 4.43:1, respectively. The benefit cost ratio of the dehydrated product using the developed machine was slight higher than that of cabinet tray dryer. The production of dehydrated samples using the developed model was economically feasible and it can be recommended for micro and small scale entrepreneurs and farmers. The detailed calculation is presented in the Appendix D and Appendix E.

CHAPTER V
SUMMARY AND CONCLUSION

Jackfruit is one of the under exploited nutritious fruits indigenous to the rainforests of western Ghats of India. In 2014-15, area under jackfruit cultivation in India was 1,49,000 ha with it's annual production of 20,37,000 T. Kerala shares 41% of the overall production of jackfruit in the country. Jackfruit has limited shelf life due to its perishable nature, inherent compositional and textural characteristics which affect the market potential. Under such circumstances, appropriate interventions in post harvest technology to ensure year around availability need to be investigated. In Kerala there is a great demand for firm fleshed '*varikka'* variety because of its taste and unique texture. Hence in the present study matured jackfruit of '*varikka'* variety was selected.

In the traditional jackfruit drying process, a protocol with separate drying and blanching units were utilised, which increased energy, process time, plant space and production costs. To circumvent these disadvantages, the present study on "Development and performance evaluation of a blancher cum dryer for jackfruit" was envisaged with specific objectives of development of blancher cum dryer, performance evaluation, as well as standardisation of process and quality parameters of jackfruit slice production.

To avoid the drudgery of workers, a prototype blancher cum dryer with volume of 1.210 m^3 was developed and fabricated using a SS 304 sheet and SS tubes by TIG welding. The developed blancher cum dryer mainly consisted of steam chamber, drying chamber, frame assembly, water heaters, air heating coils and blowers. The frame was provided with twelve compartments to accommodate twelve stainless steel trays. The performance of blancher cum dryer was evaluated in terms of capacity at three different loading (18, 23 and 28 kg), energy required for steam production, blanching, and drying. Samples were dipped in preservatives such as

citric acid (0.1, 0.2 and 0.3%), KMS (0.1%) and turmeric powder (0.1, 0.3 and 0.5%) at different concentrations for reducing the browning reactions and to decrease the drying time. Steam blanching process was carried out at 80°C for selected timings (6, 7, 8 and 9 min). Blanching time and pretreatments were standardised based on the enzyme inactivation texture and colour retention.

Blanched samples were dried in twelve perforated trays at different combinations. In the developed blancher cum dryer, steaming chamber was provided with a capacity of 60 *l*. The matured jackfruit slices of 7.62 ± 0.33 mm were placed on twelve perforated trays of developed blancher cum drier at three different loading rates selected for the investigation were 18, 23 and 28 kg and 12, 15.5 and 18 kg in developed combo drier and cabinet dryer, respectively. The blanching process was carried out at 80°C, blanching time varies as loading rate varies the minimum blanching time of 7 min was recorded at 18 kg loading. Complete enzyme inactivation occurred at C7 treatment (Steam blanching + 0.2% citric acid + 0.1% KMS + 0.5% Turmeric powder). Blanching time and preservatives were standardised based on the negative result obtained in hydrogen peroxide test, catalase test and the results of the quality parameters like texture and colour. The colour values of *L**, *a** and *b** at standardised blanching time were 72.32, 2.35 and 41.2 respectively. Firmness and toughness values of blanched samples were 4.56 N and 0.72 N.sec, respectively.

Drying experiments were conducted for the standardised pretreatment and time in blancher cum dryer with an air velocity of 2.8-3.2 m/s, until it reaches below 10% (w.b.). After drying, the samples were packed in LDPE 100 µm bags and stored in the ambient atmospheric conditions. The quality parameters were determined for all the combinations initially and during the storage at every one month interval up to ten months. Data analysis was performed and the best treatment was optimised using the general factorial design in Design-Expert software version 7.0.

The results drying studies showed that, as the drying temperature increased from 60-70°C, drying time decreased significantly due to increased heat transfer. Drying duration varied with loading rate and drying temperature, which ranges between 300 to 480 min. An increase in drying time was observed for control sample compared to blanched and treated samples.

The moisture content of jackfruit slices was decreased from 317.53% (d.b.) to 7.94% (d.b.) in seven hours at 60 ± 2°C drying temperature. In case of 65 ± 2°C drying temperature six and half hours was required to decrease the moisture content from 351.26% (d.b.) to 7.61% (d.b.), whereas at 70 ± 2°C drying temperature, five hours was required to decrease the moisture content from 328.44% (d.b.) to 7.15% (d.b.). The drying rate showed that entire drying process occurred at the falling rate period. At higher drying temperature the shorter the drying times were required to reach the desired final moisture content.

Among the four tested drying models namely Newton, Page, Henderson-Pabis and Logarithmic models, the Page model was described as the best fit to the experimental data with highest R^2 value of 0.998 and lower χ^2, SSE and RMSE values of 0.013475, 0.002529 and 0.01516, respectively at 60°C drying temperature. At 65°C drying temperature, R^2 value of 0.9973 and χ^2, SSE and RMSE values of 0.000304, 0.003651 and 0.01744, respectively, was observed. At 70°C drying temperature, R^2 value was 0.9951 and χ^2, SSE and RMSE values were 0.000601, 0.006017 and 0.02586, respectively.

Storage study was conducted for the dehydrated jackfruit samples upto ten months. The quality of the processed samples were assessed in terms of moisture content, water activity, TSS, pH, vitamin C, texture, colour and microbial analysis at every one month interval. The moisture content of samples showed increasing trend during the storage period from 0 to 10 months. The maximum increase in moisture content was observed in 23 kg loading rate at 70°C drying temperature (11.26%) and

minimum was recorded both in 23 kg loading rate at 65°C drying temperature and 28 kg loading rate at 70°C drying temperature with 9%. This increase in moisture during storage might be due to the absorption of moisture from surroundings due to low equilibrium moisture content and hygroscopic nature of dehydrated product.

The water activity of the dehydrated samples was increased significantly during storage period. The maximum a_w was noticed in the18 kg loading rate at 60°C drying temperature (0.598) combination and minimum water activity was observed in 23 kg loading rate at 65°C drying temperature (0.548). Water activity of dehydrated slices was in the safe level (<0.6) during the storage period. The pH value of dehydrated slices was decreased towards the ten months of storage period. This is due to the decline in the acidic compounds during storage. The highest pH content was recorded in 18 kg loading rate at 60°C drying temperature (5.53). The lowest pH value was noticed in 23 kg loading rate at 65°C drying temperature (4.75).

The drying temperature significantly affected the vitamin C content; it was decreased from 9.104 to 6.913 mg/100 g. This was due to the thermal degradation and oxidation occurred during drying and storage respectively. Higher vitamin C was noticed in 23 kg loading rate at 60°C drying temperature (8.15 mg/100 g) and significant reduction was noticed, in 28 kg loading rate at 70°C drying temperature (5.78 mg/100 g). This might be due to the oxidative and non oxidative changes, light and temperature during the storage. The highest mean TSS was noticed at end of storage period (13.85°B) while the lowest mean value recorded at initial stage of storage (9.611°B). The storage period had significant effect on the firmness of the dehydrated samples; firmness was decreased as the storage period increased. The texture values were mainly dependent on the water activity. Rehydration ratio of the dehydrated jackfruit slices were decreased with increase in moisture content. At the end of storage period maximum rehydration ratio was observed in 28 kg loading rate and 60°C drying temperature (1.012) and minimum was noticed in control sample

(0.725). As the drying temperature increased, a reduction in rehydration ratio was observed. This might be due to faster drying rates which were responsible for the physico - chemical changes in the samples.

In general L* and b* values were decreased and a* value increased during the storage period. A decrease in L* values was noticed at low drying temperature and increased drying period. The combination of 23 kg loading rate at 60°C drying temperature (83.16) had maximum mean L* value. The loading rate of 23 kg at 60°C drying temperature (1.54) combination obtained the lowest a* value at the end storage period. The increase in a* value was due to the non enzymatic browning. Maximum b* value was noticed in 18 kg loading rate at 65°C drying temperature (31.86) compared to control (21.34) with low b* value. This was due to treatment with turmeric powder. Curcuminoids present in turmeric are natural phenols responsible for yellowness of jackfruit slices. Minimum ΔE value was noticed in 18 kg loading rate at 65°C drying temperature (2.83) combination at the end of storage period.

At the end of the storage period sample retained with most quality parameters and microbiologically safe were selected for sensory evaluation. From the sensory evaluation, it was concluded that 23 kg loading rate at 60°C drying temperature was the best judged combination, in terms of colour and appearance, taste, flavour, texture and overall acceptability compared to all the combinations.

The cost of operation per kg of dehydrated jackfruit slices for developed blancher cum dryer and cabinet tray dryer were Rs.172/- and 180/-, respectively. The present study will definitely ensure the economic security for jackfruit growers and small scale entrepreneurs, by the way of assuring income and employment generation. Also it adds to the diversified alternative food item in dietary means. This will undeniably place a significant role in the market.

REFERENCES

Abano, E.E. and Sam-Amoah, L.K. 2011. Effects of different pretreatments on drying characteristics of banana slices. *ARPN J. Eng. Appl. Sci.* 6 (3): 121-129.

Adams, M.R. and Moss, M.O. 2000. Food Microbiology. Royal Society of the Chemistry, Cambridge, UK, 479p .

Akbari, S.H. and Patel, N.C. 2006. Optimization of parameters for good quality dehydrated onion flakes. *J. Food Sci. Technol.* 43(6): 603-606.

Akhila, B.G. and Shareena, K.P. 2009. Product diversification of jackfruit *(Artocarpusheterophyllus L.)* B.Tech (Agri eng.) Project. Kerala Agricultural University, Thrissur, 50p.

Akpan, G.E., Onwe, D.N., Fakayode, O.A., and Offiong, U.D. 2016. Design and Development of an Agricultural and Bio-materials Cabinet Tray Dryer. *Int. J. Food Eng. Technol.* 2(1): 34-42.

Alam, S., Gupta, K., Khaira, H., and Javed, M. 2013. Quality of dried carrot pomace powder as affected by pretreatments and methods of drying. *Agric. Eng. Int. CIGR J.* 15(4): 236-243.

Ali, M., Shahin, R., Zahra, E.D., and Alireza, K. 2008. Kinetic models for colour changes in kiwifruit slices during hot air drying. *World J. Agric. Sci*. 4(3): 376-383.

Amerine, M.A., Pangborn, R.M., and Roessler, E.B. 1965. *Principles of Sensory Evaluation of Food* (Academic Press) London. 5p.

Anonymous. 2015. Agricultural and Processed Food Products Export Development Authority (APEDA).

Antarkar, A.V. 1991. Studies on physico-chemical composition, storage and processing of jackfruit (*Artocarpusheterophyllus L.*). A M.Sc. (Agri.) thesis

submitted to Konkan Krishi Vidyapeeth, Dapoli; Dist. Ratnagiri, Maharashtra State.

Association of Official Analytical Chemists (AOAC), 2005. *Official Methods of Analysis of the AOAC International*.18thedn. Gaithersburg, MD, USA.

Azeredo, H., Brito, E.S., Moreira, G., Farías, V. L., and Bruno, L. M. 2006. Effect of drying and storage time on the physico-chemical properties of mango leathers. *Int. J. Food Sci. Technol.* 41: 635-638.

Bal, A., Sandhu, K.S., and Ahluwalia, P. 2002. Studies on suitability of cultivars, frying medium and packaging for potato chips. *J. Food Sci. Technol.* 39: 394-402.

Bevilacqua, M., Ciarapica, F.E., and Polonara, F. 2012. Design and optimization of a new experimental blancher. *J. Food Control*. 28: 122-130.

Bhatia, B.S., Siddapa, G.S., and Lal, G. 1955. Composition and nutritive value of jackfruit. *Indian J. Agric. Sci.* 25: 303-306.

Bhatt, K.C. 2009. Development of a steam blancher for vegetables. M tech thesis.Chaudhary Charan Singh Haryana Agricultural University *Hissar.* 108p.

Biworo, A., Tanjung, E., Iskandar, Kharini., and Suhartono, E. 2015. Antidiabetic and antioxidant activity of jackfruit (*Artocarpusheterophyllus L.*) extract. *J. Med. Bioeng.* 4(4): 318-323.

Callegarin, F., Quezada, G.J.A., Debeaufort, F., and Voilley, A. 1997. Review: lipids and bio packaging. *J. Am. Oil Chem. Soc.* 74: 1183-1192.

Canet, W. and Hill, M.A. 1987. Comparison of several blanching methods on the texture and ascorbic acid content of frozen potatoes. *Int. J. Food Sci. Technol.* 22: 273-277.

Cano-Chauca, M., Ramos, A. M., and Stringheta, P.C. 2002. Colour and texture evaluation during banana drying *(Musa sppnanica (AAA). Alimentaria.* 329: 153-158.

Chin, H.B. and Dudek, J.A. 1988. In Vegetable processing, AVI Book Publishing CO., New York, 649p.

Darabi, H., Zomorodian, A., Akbari, M.H., and Lorestani, A.N. 2015. Design a cabinet dryer with two geometric configurations using CFD. *J. Food Sci. Technol.* 52(1): 359-366.

Demir, V., Gunhan, T., Yagcioglu, A.K., and Degirmencioglu, A. 2004. Mathematical modelling and the determination of some quality parameters of air-dried bay leaves. *Biosyst. Eng.* 88(3): 325-335.

Doymaz, I. 2004. Effect of pre-treatments using potassium metabisulphite and alkaline ethyl oleate on the drying kinetics of apricots. *Biosys. Eng.* 89: 281-287.

Doymaz, I. 2007. The kinetics of forced convective air-drying of pumpkin slices. *J. Food Eng.* 79: 243-248.

Doymaz, I. 2010. Effect of citric acid and blanching pre-treatments on drying and rehydration of Amasya red apples. *Food bioproducts processing.* 88: 124-132.

Doymaz, I. and Ismail, O. 2011. Drying characteristics of sweet cherry. *Food Bioprod Process*; 89: 31–38.

Doymaz, I. 2014. Drying kinetics and rehydration characteristics of convective hot-air dried white button mushroom slices. *J. Chem.*1-7.

Erdman, W.J. and Klein, P.B. 1982. Harvesting, Processing, and Cooking Influences on Vitamin C in Food, In Ascorbic Acid: Chemistry, Metabolism, and Uses, Seib, P.A. and Tolbert, B.M. (Eds.), American Chemical Society, Washington D.C., pp. 499-532.

Eskin, N.A.M. 1979. Plant pigments, flavours and textures. The Chemistry and Biochemistry of Selected Compounds. Academic Press, London.

FAO, 2004. Processed Foods for Improved Livelihoods. Food and Agriculture Organization Corporate Repository Originated by Agriculture and Consumer Protection Unit.

Fellows, P. 2000. *Food Processing Technology-Principles and Practice*, second (ed.) Boca Ratton, Florida.

Gan, P.L. and Poh, P.E. 2014. Effect of Shapes on the Drying Kinetics and Sensory Evaluation Study of Dried Jackfruit. *Int. J. Sci. Eng.* 7(2): 193-198.

Giraldo-Zuniga, A.D., Arevalo-Pinedo, A., Rodrigues, R.M., Lima, C.S.S., and Feitosa, A.C. 2006. Kinetic drying experimental data and mathematical model for jackfruit (*Artocarpusheterophyllus L.*) slices. *CyTA- J. Food.* 5: 89-92.

Global Village Fruit. 2013. Introducing Jackfruit, the Wonderfuit (TM) of the World, USA: GlobalVillageFruit;th http://www.globalvillagefruit.com (Accessed 17 May 2014).

Goncalves, E.M., Pinheiro, J., Abreu, M., Brandao, T.R.S., and Silva, C.L.M. 2010. "Carrot (*Daucuscarota L.*) peroxidase inactivation, phenolic content and physical changes kinetics due to blanching," *J. Food Eng.* 97(1): 574-581.

Haq, N. 2006. Jackfruit. Monograph of International Centre for Underutilised Crops (ICUC).

Henriette, M.C., Azeredo, E.S., Brito, E.G., Germano, M., and Burno, V.I. 2006. Effect of drying and storage time on the physico-chemical properties of mango leathers. *Int. J. Food Sci. Technol.* 41(6): 635-638.

Heras-Ramirez, M.E., Quintero-Ramos, A., Camacho-Davila, A.A., Barnard, J., Talamas-Abbud, R., Torres-Munoz, J.V., and Salas-Munoz, E. 2012. Effect of

Blanching and Drying Temperature on Polyphenolic Compound Stability and Antioxidant Capacity of Apple Pomace. *Food Bioprocess Technol.* 5: 2201-2210.

Hosamani, R., Jagadeesh, S.L., Suresha, G.J., and Tummaramatti, S. 2016. Fortification of Carrot, Jackfruit and Aonla Powder to Enhance Nutritional and Sensory Qualities of Sweet Biscuits. *J. Nutr. Health Food Eng.* 4(3): 00130.

Hossain, M.T., Hossain, M.M., Sarker, M., Shuvo, A.N., Alam, M.M., and Rahman, M.S. 2014. Development and quality evaluation of bread supplemented with jackfruit seed flour. *Int. J. Food Sci.* 3(5): 484-487.

Idah,P.A., Obajemihi, O.I., Adeboye, O.A., and Olaniyan, A.M. 2014. Assessment of Osmotic Pre-Drying Treatment on Drying Rates of Fresh Tomato Fruits. *Nigerian J. Technol. Develop.*11(1): 22-26.

Jagadeesh, S.L., Reddy, B.S., Hegde, L.N., Swamy, G.S.K., and Raghavan, G.S.V. 2006.Value addition in jackfruit (*Artocarpusheterophyllus L.).*Paper number 066135.

Jagtap, U.B., Panaskar, S.N, and Bapat, V.A. 2010. Evaluation of antioxidant capacity and phenol content in jackfruit (*Artocarpusheterophyllus L.*) fruit pulp.*Plant Food Hum Nutr.* 65: 99-104.

John, R. 2004. Lignins: Natural polymers from oxidative coupling of 4-hydroxyphenyl- propanoids. *Phytochem.Review.* 3: 29-60.

Jose, C.J.I.R.D., Ralph, P.C., and Joseph, R.P. 2004. Blanching of Foods. Washington State University, Pullman, Washington, U.S.A.

Kabiru, A.A., Joshua, A. A., and Raji, A.O. 2013. Effect of slice thickness and temperature on the drying kinetics of Mango (*Mangifera Indica*). *Int. J. Res. Rev. Appl. Sci.* 15: 41-50.

Kaushal, P., and Sharma, H.K. 2016.Osmo-convective dehydration kinetics of jackfruit (*Artocarpusheterophyllus L.*). *J. Saudi Society Agric. Sci.* 15: 118-216.

Kessy, H.N.E., Zhuoyan Hu, Zhao, L., and Molin, Z. 2016. Effect of Steam Blanching and Drying on Phenolic Compounds of Litchi Pericarp.*Molecules*. 21(729): 1-9.

Kha, T.C., Nguyen, M.H., and Roach, P. D. 2011. Effects of Pre-Treatments and Air Drying Temperatures on Colour and Antioxidant Properties of Gac Fruit Powder. *Int. J. Food Eng.* 7(3): 1-14.

Kumar, M., Kasana, K.S., Kumar, S., and Prakash, O. 2011. Experimental investigation on convective heat transfer coefficient for khoa drying. *Int. J. Curr. Res.* 3(8): 088-093.

Kumar, P.S. and Sagar, V.R. 2016. Effect of Packaging Materials and Storage Temperature on Quality of Osmo-vac Dehydrated Guava Slices During Storage. *Proc. Natl. Acad. Sci., India, Sect. B Biol. Sci.* 86(4): 869-876.

Lee, C.Y., Bourne, M.C., and Buren, V.J. P. 1979. Effect of blanching treatments on the firmness of carrots. *J. Food Sci*, 44: 615-616.

Lewicki, P.P. 1998. Effect of pre-drying treatment, drying and rehydration on plant tissue properties: a review. *Int. J. Food Prop.* 1 (1): 1-22.

Llano, K.M., Haedo, A.S., Gerschenson, L.N., and Rojas, A.M. 2003. Mechanical and biochemical response of kiwifruit tissue to steam blanching. *Food Res. Int. 36:* 767-775

Loha, C., Choudhury, B., Chatterjee, P.K., and Datta, A.B. 2008. Development of tray dryer for processing ginger for the rural people of mizoram.Conference Paper.Lund, D.B. (Eds.), *Handbook of Food Engineering*.New York: Marcel Dekker.

Manikantan, M.R., Sharma, R., Kasturi, R., and Varadharaju, N. 2014. Storage stability of banana chips in polypropylene based nanocomposite packaging films. *J. Food Sci. Technol.* 51(11): 2990–3001.

Martinez-Ferrer, M., Harper, C., Perez-Munoz., and Chaparro, M., 2002. Modified atmosphere packaging of minimally processed mango and pineapple fruits. *J. Food Sci.* 67(9): 3365-3371.

Martynenk, A and Janaszek, M.A. 2014. Texture changes during drying of apple slices. *Drying Technology*, 32: 567-577.

Master, A.A., Knott, E.R., Teunissen, P.G.M., and Bartels, P.V. 2000. Effects of high isostatic pressure on mushrooms. *J. Food Eng.* 45(1): 11-16.

Meisami-asl, S.E., Rafiee, A., Keyhani, and Tabatabaeefar, A. 2010. Determination of suitable thin layer drying curve model for apple slices (variety-Golab). *Plant omics J.* 3(3): 103-108.

Midilli, A. and Kucuk, H. 2003. Mathematical modeling of thin layer drying of pistachio by using solar energy. *Energy Conversion and Management.* 44(7): 1111–1122.

Mohsenin, N.N. 1986. *Physical Properties of Plant and Animal Materials: Structure, Physical Characteristics, and Mechanical Properties.* Gordon and Breach, Science Publishers Inc., New York. 891.

Molla, M.M., Nasrin, T.A.A., Islam, M.N., and Bhuyan, M.A. J. 2008. Preparation and packaging of jackfruit chips. *Int. J. Sustain. Crop Prod.* 3(6):41-47.

Moser, U. and Bendich, A. 1991. “Vitamin C”, In Handbook of Vitamins, Machlin, L.J. (Ed.), 2nd ed., Marcel Dekker, New York, 195-231.

Murphy, M.G., Skonberg, D.I., Camire, M.E., Dougherty, M.P., Bayer, R.C., and Briggs, J.L. 2003.Chemical composition and physical properties of extruded snacks containing crab-processing by-product. *J. Sci. Food Agric*. 83: 1163-1167.

Mwithiga, G. and Olwal, J.O. 2005. The drying kinetics of kale (*Brassica oleracea*) in a convective hot air dryer. *J. Food Eng.* 71(4): 373–378.

Nakasone, H.Y. and Paull, R. E. 1998. Tropical fruits. Wallingford: CAB International, pp. 334-341

Narasimham, P. 1990. Breadfruit and jackfruit. In: Nagy S, Shaw PE, Wardowski WF, editors, *Fruits of tropical and subtropical origin Lake Alfred*, FL: Florida Science Source. pp.193-259.

National horticulture board. 2015. http://apeda.in/agriexchange/India%20Production/India

Ndiaye, C., Xu, S., and Wang, Z. 2009. Steam blanching effect on polyphenoloxidase, peroxidase and colour of mango (*Mangifera indica L.)* slices. *Food Chem*, 113: 92–95.

Negi, P.S. and Roy, S.K. 2000. Effect of blanching and drying methods on beta-carotene, ascorbic acid and chlorophyll retention of leafy vegetables, *LebensmWissTechnol*, 33: 295-298.

Nirmala, R. 2010. Minimal processing of selected fruits, vegetables and green leafy vegetables. M.Tech (Ag) thesis, Tamil Nadu Agricultural University, Coimbatore, 124p.

Okos, M.R., Narasimhan, G., and Singh, R.K. 1992. Food dehydration conditions on the physical properties of impregnated orange peel. *Brazilian J. Chem. Eng.* 30(3): 667 – 676.

Ong, S.P., Law, C.L., and Hii, C.L. 2012. Effect of pre-treatment and drying method on colour degradation kinetics of dried salak fruit during storage.*Food and Bioprocess Technol.* 5 (6): 2331–2341.

Padmavathi, D. 2015. Optimization of process parameters for vacuum drying of ripe jackfruit bulb (*Artocarpusheterophyllus L.*).Unpublished M.Tech thesis. Kerala Agricultural University, Thrissur, 134p.

Pan, Z., Olson, D.A., Amaratunga, K.S.P., Olsen, C.W., Zhu, Y., and Tara, H. 2005. Feasibility of using infrared heating for blanching and dehydration of fruits and vegetables.An ASAE (American Society of Agricultural Engineers) Meeting Presentation.

Parab, B.P. 1992. Studies on some aspects of utilization of cashew (*AnacardiumoccidentaleL.*) wastes. A thesis submitted to the Konkan Krishi Vidyapeeth Dapoli, Dist: Ratnagiri, Maharashtra State.

Patil, R.R. 2012. Studies on dehydration of mature jackfruit (*Artocarpusheterophyllus L.)* chips for value addition. M.Tech thesis submitted to Dr. BalasahebSawant Konkan KrishiVidyapeeth, Dapoli, Dist. Ratnagiri, Maharashtra State.

Patil, R.R., Khanvilkar, M., Mokat, D.N., Relekar, P.P., and Pujari, K.H. 2014. Effect of pre-treatments on physico-chemical composition of dehydrated jackfruit chips during storage at ambient temperature. *Life Sci. Leafl.*54: 27-35.

Patil, R.S. 2003. Studies on physico-chemical composition, storage, processing and waste utilisation of jackfruit (*Artocarpusheterophyllus L.*). A Ph. D. thesis submitted to Dr. Balasaheb Sawant Konkan KrishiVidyapeeth, Dapoli, Dist. Ratnagiri, Maharashtra State.

Patricia, A.D., Patricia, A.K., Yohan, Y., and John, N.S. 2007. Influence of modified blanching treatments on inactivation of Salmonella during drying and storage of carrot slices. *Food Microbiol.*24: 500–507.

Patro, K.T.S.K.K., and Emmanuel, N. 2014.Impact of chemicals, blanching and storage period on rehydration of dehydrated kakrol. *Ind. J. Plant Sci.* 3(4): 9-13.

PFA. 2000. Prevention of Food Adulteration Act, 1954 and Rules, 1956. *Microbiological requirements of food products*.Published by Confederation of Indian Industries.

Phungamngoen, C., Chiewchan, N., and Devahastin, S. 2013. Effects of various pretreatments and drying methods on Salmonella resistance and physical properties of cabbage. *J. Food Eng.*115: 237- 44.

Piga, A., Pinna, I., Ozer, K.B., Agabbio, M. and Aksoy, U. 2004. Hot air dehydration of figs (*Ficuscarica L.*): drying kinetics and quality loss. *Int. J. Food Sci Technol.* 39: 793-799.

Prajapati, V.K., Nema, P.K., and Rathore, S.S. 2009. Effect of pretreatment and recipe on quality of solar dried aonla (*Emblica officinalis Gaertn*) shreds. In: Int Conference on Food security and environmental sustainability. Indian Institute of Technology, Kharagpur, December. 17–19.

Prajapati, V.K., Nema, P.K., and Rathore, S.S. 2011. Effect of pretreatment and drying methods on quality of value-added dried aonla (*Emblica officinalis Gaertn*) shreds. *J. Food Sci. Technol.* 48(1): 45–52.

Praveena, N. and Sudheer, K.P. 2015.Optimization of blanching treatment for '*koozha*' variety tender jack fruit (*Artocarpusheterophyllus L.*). *Int. J. Agric. Sci. Res.* 5(6): 131-138.

Praveena. N. 2015. Development and quality evaluation of retort pouch packed tender jackfruit (*Artocarpusheterophyllus L.*). Unpublished M.Tech thesis. Kerala Agricultural University, Thrissur, 164p.

Pritty, S.B, Sudheer, K.P., Santhi, M.M., Divyasree, P.S., and Anu, S.C. 2014. Development and quality evaluation of canned tender jackfruit

(*ArtocarpusheterophyllusL.*).*Proceedings of the International symposium on jackfruitand breadfruit of the tropics: genetic diversity, management, value additionand marketing strategies.* 15-16 may, UAS, Bangalore.7p.

Pritty, S.B. and Sudheer, K.P. 2012. Optimization of blanching process for tender jack fruit. *Indian J. Dairy Bio Sci.* 23(1): 14-21.

Pritty, S.B., Sudheer, K.P., Bindu, J., and Anu, V. 2013. Safety and quality aspect of thermal processed tender jackfruit. Proceedings of 3rd International conference on food technology. (INCOFTECH-2013), Food processing technologies-challenges and solution for sustainable food security, pp. 507-513.

Pua, C.K., Hamida, N.S.A., Tanb, C.P, Mirhosseini, Rahmanb, H.R.A., and Rusul, G. 2008. Storage stability of jackfruit (*Artocarpusheterophyllus L.*) powder packaged in aluminium laminated polyethylene and metallized co-extruded biaxially oriented polypropylene during storage. *J. Food Eng.* 89: 419-428.

Rahman, M.M., Kibria, G., Bhuiyan, Z.H., Chowdhury, K., Khan, S., and Karim, R. 2007. Studies on the relation between water activity and sensory qualities as well as chemical changes of coriander (*Coriandrunsativum*) powder in flexible packaging films. Bangladesh *J. Sci. Ind. Res.* 42 (1): 53–58.

Rahman, S.N.F., Wahida, R., Norazah, A., and Rahmana. 2015. Drying Kinetics of Rambutan *(Nephelium Lappaceum)* in a Drying Oven. *Procedia - Social and Behavioral Sci.* 195: 2734-2741.

Ramachandra, C.T. and Rao, P.S. 2009. Modelling and optimization of drying variables of Aloe vera (*Aloe barbadensis* Miller) gel. Paper presented at *ASABE Annual Meet* held at Reno, Nevada, USA during June 21-24, paper No. 096498.

Ramana, S.V. and Taylor, A.J. 1994. Effect of various agents on rheological properties of carrot cells and protoplasts. *J. Sci. Food Agric.* 64: 519–525.

Ramarjuna, M.N., and Jayaraman, K. S. 1980. Studies on the preparation and storage stability of intermediate banana. *J. Food Sci. Technol*, 17:183.

Ranganna, S. 1995. *Hand Book of Analysis and Quality Control for Fruit and Vegetable Products* (1st Ed.). Tata Mc Graw hill publishing Co, Ltd., NewDelhi.

Rao, K.V.S.S., Thompkinson, D.K. and Mathur, B.N. 1997. Role of sensory analysis in product development.*Indian Food Industry.* 16(1): 53-57.

Reddy, B.M.C., Patil, P., Shashikumar, S., and Govindraju, L.R., 2004. Studies on physic-chemical characteristics of jackfruit clones of South Karnataka.*Karnataka J. Agric Sci.* 17(2): 279-282.

Robertson, G. L. 2006. *Food packaging: Principles and practice* (2nd Ed.). Boca Raton, FLA: Taylor and Francis. 432p.

Roy, S.K., and Joshi, G.D. 1995. Minor fruits-tropical. In: Salunkhe DK, editor. *Handbook of fruit science and technology*. New York, USA: Marcel Dekker, Inc. pp. 570–583.

Sabikhi, L. and Tiwari, B.D. 1999. Factors in food frying.*Indian Food Industry*. 18: 100–104.

Sadasivam, S. and Manickam, C. 1992. *Biochemical Methods for Agricultural Science* (1st Ed.).Wiley Eastern Limited, New Delhi. 780p.

Sadhu and Chattopadhyay. 2001. Introductory fruit crops. 6-9.

Salunkha, D.K., Jadhar, S.J., and Yu, M.H. 1974. Quality and nutritional composition of tomato fruits influenced by certain biochemical and physiological changes. *Qualitas plant*. 24(1): 85-113.

Samaddar, H.N. 1985. Jackfruit. In: Bose, T.K. (Ed.), *Fruits of India: Tropical and Subtropical.* NayaProkash, Calcutta, pp. 487-497

Sandhu, K. S., Bhatia, B.S., and Shukla, F.C. 1985. Physico-chemical changes during storage of kinnow mandarin and pineapple juice concentrate. *J. Food Sci. Technol.* 22:342-345.

Sandhu, K.S. and Bawa, A.S. 1993. Requirements for quality potato chips - an overview. *Indian Food Ind.* 12: 47–50.

Sathishkumar, S., and Karthik, S. 2015. Optimization of temperature and time of deep fat frying for quality jackfruit chips. *Int. J. Agric. Sci. Res.* 5(6): 119-124.

Sawant, S.B. 2000. Studies on maturity indices and some aspects of post harvest handling and processing of jackfruit. A M.Sc. (Agri.) thesis submitted to the Konkan KrishiVidyapeeth, Dapoli. Dist. Ratnagiri, Maharashtra State.

Saxena A., Bawa A. S., and Raju P. S. 2008. Use of modified atmosphere packaging to extend shelf-life of minimally processed jackfruit (*Arotocarpusheterophyllus L.*) bulbs. *J. Food Eng.* 8(4): 455-466.

Saxena, A., Bawa, A.S. and Raju, P.S. 2009. Multitarget preservation techniques of jackfruit. *J. Food Eng*. 91: 18-28.

Saxena, A., Maity, T., Raju, M.S., and Bawa, A.S. 2012. Degradation kinetics of Colour and Total Carotenoids in Jackfruit (*Artocarpusheterophyllus L.*) Bulb slices during hot air drying. *Food and Bioprocess Technol.* 5: 672-679.

Saxena, J. and Dash, K.K. 2015. Drying kinetics and moisture diffusivity study of ripe Jackfruit. *Int. Food Res. J.* 22(1): 414-420.

Severini, C., Baiano, A., Pilli T.D., Carbone, B.F., and Derossi, A. 2005. Combined treatments of blanching and dehydration: study on potato cubes. *J. Food Eng.* 68(3): 289-296.

Sharma, G.K., Semwal, A.D., and Arya, S.S. 2000. Effect of processing treatments on the caratenoids composition of dehydrated carrots. J. Food Sci. Technol. 37(2): 196-200.

Shivhare, U.S., Gupta, M., Basu, S., and Raghavan, G.S.V. 2009. Optimization of blanching process for carrots. *J. Food Pro. Eng.* 32: 587-605

Sloan, M.L.R., Dunn, L.K., Jefferies, O.A., Pike, Sarah, Barrows, E.N., and Steele, F.M. 2016. Effect of water activity and packaging material on the quality of dehydrated taro (*Colocasiaesculenta L.) Schott*) slices during accelerated storage. *Int. J. Food Sci.* 9p.

Sobukola, O.P., Dairo, O.U. and Odunewu, A.V. 2008. Convective hot air drying of blanched yamslices. *Int. J. Food Sci. Technol.*43: 1233–1238.

Swami, S.B., Thakor, N.J., Haldankar, P.M., and Kalse, S.B. 2012. Jackfruit and its many functional components as related to human health: A Review, *Comprehensive Reviews in Food Science and Food Safety*. 11: 565-576.

Swami, S.B., Thakor, N.J., Orpe, S., and Kals, S.B. 2016. Development of ripe jackfruit bulb powder and its quality evaluation. *J. Food Res. Technol.* 4 (1): 22-29.

Taib, M.R., Ida, I.M., Chee L.N., and Pang, S.N. 2013. Drying kinetics, rehydration characteristics and sensory evaluation of microwave vacuum and convective hot air dehydrated jackfruit bulbs. *J. tekno* 65(1): 51–57.

Taylor, A.J., Brown, J.N. and Downie, L.M. 1981. The effect of processing on the texture of canned mung bean shoots. *J. Sci. Food Agric.* 32, pp.134-138.

Teja, R., Santhi, K.K and Narsingarao, A. 2016. Edible film coating of fresh cut jackfruit. *Int. J. Sci. Envi. Technol.* 5(3): 1658-1668.

Thiagu, R., Nagin, C. and Ramana, K.V. 1993. Evolution of mechanical characteristics of tomatoes of two varieties during ripening. *J. Food Agric*. 2(62): 175-183.

Timbers, G.E., Stark, R., and Cumming, D.B. 1984. A new blanching system for the food industry: design, construction and testing of a pilot plant prototype.

Tunde-AkintundeT.Y., and Ogunlakin G.O. 2013. Mathematical modeling of drying of pretreated and untreated pumpkin. *J. Food Sci. Technol.* 50: 705–713.

Tunde-Akintunde, T.Y., Akintunde, B.O., and Fagbeja, A. 2011. Effect of blanching methods on drying kinetics of bell pepper. *Afr. J. Food Agric. Nutr.Dev.* 11(7): 5457-5474.

Wang, Z., Sun, J., Liao, X., Chen, F., Zhao, G., Wu, J., and Hu, J. 2007.Mathematical modeling on hot air drying of thin layer apple pomace. *Food Res. Int.* 40: 39-46.

APPENDIX A1

Table A1 ANOVA table for effect of blanching time and preservatives on firmness

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob>F	Std. Dev.	C.V. (%)	R^2
Model	437.19	29	15.08	275.83	<0.0001	0.23	4.09	0.9926
A-preservatives	410.84	9	45.65	835.23	<0.0001			
B-Time	14.65	2	7.33	134.05	<0.0001			
AB	11.70	18	0.65	11.89	<0.0001			
Pure Error	3.28	60	0.055	**Significant**				
Cor Total	440.46	89						

APPENDIX A2

Table A2 ANOVA table for effect of blanching time and preservatives on toughness

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob>F	Std. Dev.	C.V. (%)	R^2
Model	104.75	29	3.61	702.91	<0.0001	0.072	4.85	0.9971
A-preservatives	*88.57*	9	9.84	1915.05	<0.0001			
B-Time	*0.98*	2	0.49	95.16	<0.0001			
AB	15.20	18	0.84	164.37	<0.0001			
Pure Error	0.31	60	5.139E-003	**Significant**				
Cor Total	105.06	89						

APPENDIX A3

Table A3 ANOVA table for effect of blanching time and preservatives on Lightness value (L*)

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob>F	Std. Dev.	C.V. (%)	R^2
Model	56.00	29	1.93	0.25	0.9999	2.75	3.82	0.1096
A-preservatives	41.22	9	4.58	0.60	0.7887			
B-Time	7.90	2	3.95	0.52	0.5965			
AB	6.87	18	0.38	0.050	1.0000			
Pure Error	454.97	60	7.58	**Not Significant**				
Cor Total	510.96	89						

APPENDIX A4

Table A4 ANOVA table for effect of blanching time and pretreatment on redness/ greenness value (a*)

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob>F	Std. Dev.	C.V. (%)	R^2
Model	15.81	29	0.55	76.58	<0.0001	0.084	3.84	0.9737
A-preservatives	15.10	9	1.68	235.66	<0.000			
B-Time	0.11	2	0.056	7.90	0.0009			
AB	0.60	18	0.033	4.67	<0.0001			
Pure Error	0.43	60	7.118E-003	**Significant**				
Cor Total	16.23	89						

APPENDIX A5

Table A5 ANOVA table for effect of blanching time and pretreatment on yellowness (or) blueness value (b*)

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob>F	Std. Dev.	C.V. (%)	R^2
Model	1776.86	29	61.27	27.52	<0.0001	1.49	3.85	0.9301
A-preservatives	1742.18	9	193.58	86.94	<0.0001			
B-Time	22.55	2	11.27	5.06	0.0093			
AB	12.14	18	0.67	0.30	0.9966			
Pure Error	133.60	60	2.23	**Significant**				
Cor Total	1910.46	89						

APPENDIX A6

Table A6 Effect of pretreatments and blanching time on total colour difference (ΔE) and *Chroma*

Sl. No	**Treatments**	**ΔE**			***Chroma***		
		7 min	8 min	9 min	7 min	8 min	9 min
1	C1	-	-	-	26.27419	26.27419	26.27419
2	C2	15.5638	10.4806	16.54567	41.78044	36.73982	42.76406
3	C3	16.09376	16.14031	18.76984	42.22892	42.36152	44.92763
4	C4	19.7253	16.54334	19.27041	45.84746	42.68636	45.34671
5	C5	19.77593	15.54334	15.49274	45.80687	41.64636	41.60116
6	C6	21.48074	17.24716	19.14639	47.50918	43.43212	45.33966
7	C7	23.51713	22.90082	23.15486	49.4378	48.4046	48.69179
8	C8	16.43013	14.67402	16.16749	42.48281	40.8656	42.38555
9	C9	17.14046	22.26433	17.23684	43.23315	47.96162	43.2907
10	C10	21.45125	18.32258	18.34134	47.48794	43.60908	44.35887

APPENDIX B1

ANOVA for effect of storage period on the quality parameters of dehydrated jackfruit slices

Table B1	**Moisture content**							
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob>F**	**Std. Dev.**	**C.V. (%)**	**R^2**
Model	600.46	109	5.51	55.92	<0.0001	0.31	3.88	0.9652
A-Combinations	143.64	9	15.96	162.01	<0.0001			
B-Storage period (months)	418.00	10	41.80	424.31	<0.0001			
AB	38.83	90	0.43	4.38	<0.0001			
Pure Error	21.67	220	0.099	**Significant**				
Cor Total	622.13	329						

APPENDIX B2

Table B2	**Water activity**							
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob>F**	**Std. Dev.**	**C.V. (%)**	**R^2**
Model	0.40	109	3.706E-003	10.14	<0.0001	0.019	3.80	0.8340
A-Combinations	0.013	9	1.439E-003	3.94	<0.0001			
B-Storage period (months)	0.36	10	0.036	98.46	<0.0001			
AB	0.031	90	3.455E-004	0.95	0.615			
Pure Error	0.080	220	3.655E-004	**Significant**				
Cor Total	0.48	329						

APPENDIX B3

Table B3	pH							
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob>F**	**Std. Dev.**	**C.V. (%)**	**R^2**
Model	127.09	109	1.17	24.48	<0.0001	0.22	5.72	0.9238
A-Combinations	43.22	9	4.8	100.84	<0.0001			
B- Storage period (months)	70.89	10	7.09	148.85	<0.0001			
AB	12.97	90	0.14	3.03	<0.0001			
Pure Error	10.48	220	0.048	**Significant**				
Cor Total	137.57	329						

APPENDIX B4

Table B4	Vitamin C							
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob>F**	**Std. Dev.**	**C.V. (%)**	**R^2**
Model	363.01	109	3.33	34.83	<0.0001	0.31	3.8	0.9452
A-Combinations	159.94	9	17.77	185.85	<0.0001			
B-Storage period (months)	166.44	10	16.64	174.05	<0.0001			
AB	36.63	90	0.41	4.26	<0.0001			
Pure Error	21.04	220	0.096	**Significant**				
Cor Total	384.05	329						

APPENDIX B5

Table B5	Total soluble solids							
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob>F**	**Std. Dev.**	**C.V. (%)**	**R^2**
Model	996.72	109	9.14	46.87	<0.0001	0.44	3.88	0.9587
A-Combinations	182.83	9	20.31	104.13	<0.0001			
B-Storage period (months)	621.29	10	62.13	318.47	<0.0001			
AB	192.60	90	2.14	10.97	<0.0001			
Pure Error	42.15	220	0.20	**Significant**				
Cor Total	1039.63	329						

APPENDIX B6

Table B6	Firmness							
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob>F**	**Std. Dev.**	**C.V. (%)**	**R^2**
Model	12301.45	109	112.86	42.82	<0.0001	1.62	3.84	0.9550
A-Combinations	5854.68	9	650.52	246.80	<0.0001			
B-Storage period (months)	761.70	10	76.17	28.90	<0.0001			
AB	5685.07	90	63.17	23.97	<0.0001			
Pure Error	579.88	220	2.64	**Significant**				
Cor Total	12881.33	329						

APPENDIX B7

Table B7	Rehydration ratio							
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob>F**	**Std. Dev.**	**C.V. (%)**	**R^2**
Model	33.67	109	0.31	103.91	<0.0001	0.055	3.92	0.9809
A-Combinations	2.32	9	0.26	86.91	<0.0001			
B-Storage period (months)	30.02	10	3	1010.04	<0.0001			
AB	1.32	90	0.015	4.93	<0.0001			
Pure Error	0.65	220	2.972E-003	**Significant**				
Cor Total	34.32	329						

APPENDIX B8

Table B8	L* value							
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob>F**	**Std. Dev.**	**C.V. (%)**	**R^2**
Model	771.87	109	7.08	0.74	0.9611	3.09	3.80	0.2682
A-Combinations	390.45	9	43.38	4.53	<0.0001			
B-Storage period (months)	358.02	10	35.80	3.74	0.0001			
AB	23.40	90	0.26	0.027	1.000			
Pure Error	2105.59	220	9.57	**Not Significant**				
Cor Total	2877.45	329						

APPENDIX B9

Table B9	**a* value**							
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob>F**	**Std. Dev.**	**C.V. (%)**	**R^2**
Model	166.73	109	1.53	492.6	<0.0001	0.056	4.4	0.9959
A-Combinations	64.37	9	7.15	2303.13	<0.0001			
B-Storage period (months)	97.07	10	9.71	3125.99	<0.0001			
AB	5.29	90	0.059	18.94	<0.0001			
Pure Error	0.68	220	3.105E-003	**Significant**				
Cor Total	167.42	329						

APPENDIX B10

Table B10	b* value							
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob>F**	**Std. Dev.**	**C.V. (%)**	**R^2**
Model	4470.24	109	41.01	28.60	<0.0001	1.2	3.84	0.9341
A-Combinations	3030.89	9	336.77	234.86	<0.0001			
B-Storage period (months)	1314.21	10	134.12	93.54	<0.0001			
AB	98.14	90	1.09	0.76	0.9318			
Pure Error	315.46	220	1.43	**Significant**				
Cor Total	4785.70	329						

APPENDIX B11

Table B11	ΔE value							
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob>F**	**Std. Dev.**	**C.V. (%)**	**R^2**
Model	1668.45	99	16.85	425.13	<0.0001	0.2	4.33	0.9953
A-Combinations	541.9	9	60.21	1518.86	<0.0001			
B-Storage period (months)	1052.85	9	116.98	2950.99	<0.0001			
AB	73.31	81	0.91	22.96	<0.0001			
Pure Error	7.93	200	0.040	**Significant**				
Cor Total	1676.38	299						

APPENDIX C1

Table C1 Effect of storage period on moisture content of dehydrated samples

Combinations	Moisture content (% w.b.)											
	Storage period (months)											
	0	1	2	3	4	5	6	7	8	9	10	Mean
Control	7.28	7.56	7.89	8.2	8.31	8.45	8.86	9.23	10.03	10.36	10.65	8.80
L1T1	6.11	6.61	6.7	7.12	7.56	8.33	8.46	8.99	9.5	9.64	9.75	8.07
L1T2	5.8	5.86	5.98	6.44	7.17	7.36	7.49	7.66	8.34	8.73	9.05	7.26
L1T3	4.93	5.36	6	7.02	7.44	8.25	8.38	8.46	8.69	9.12	9.34	7.54
L2T1	6.1	6.38	6.65	7.27	7.6	7.92	8.12	8.57	8.78	9.07	9.16	7.78
L2T2	5.95	6.15	6.28	6.45	6.76	6.9	7.16	7.32	7.72	8.453	9	7.10
L2T3	6.96	7.26	7.5	8.42	8.49	8.53	8.69	9.3	10.57	11.16	11.26	8.92
L3T1	5.38	6.37	6.86	7.63	8.05	8.14	8.29	8.65	9.108	9.25	9.34	7.91
L3T2	7.62	7.82	8.01	8.18	8.61	8.97	9.45	9.88	10.58	11.07	11.12	9.21
L3T3	6.89	7.34	7.59	8.23	8.36	8.56	8.72	8.63	8.93	8.91	9	8.28
Mean	6.30	6.67	6.94	7.49	7.83	8.14	8.36	8.66	9.22	9.57	9.76	

APPENDIX C2

Table C2 Effect of storage period on water activity of dehydrated samples

Combinations	Water activity											
	Storage period (months)											
	0	1	2	3	4	5	6	7	8	9	10	Mean
Control	0.44	0.45	0.45	0.478	0.497	0.511	0.548	0.556	0.569	0.576	0.589	0.51
L1T1	0.46	0.467	0.5	0.505	0.515	0.526	0.529	0.534	0.556	0.569	0.598	0.52
L1T2	0.45	0.467	0.45	0.471	0.488	0.496	0.51	0.524	0.537	0.543	0.551	0.49
L1T3	0.44	0.462	0.47	0.496	0.506	0.512	0.525	0.529	0.532	0.549	0.556	0.50
L2T1	0.47	0.479	0.48	0.494	0.508	0.519	0.525	0.529	0.532	0.545	0.558	0.51
L2T2	0.47	0.479	0.48	0.488	0.488	0.497	0.502	0.518	0.529	0.535	0.548	0.50
L2T3	0.46	0.47	0.48	0.496	0.516	0.526	0.53	0.532	0.545	0.552	0.559	0.51
L3T1	0.47	0.469	0.48	0.485	0.494	0.504	0.512	0.524	0.536	0.549	0.567	0.50
L3T2	0.46	0.479	0.48	0.495	0.5	0.503	0.517	0.526	0.53	0.542	0.565	0.51
L3T3	0.45	0.474	0.49	0.497	0.509	0.528	0.536	0.514	0.531	0.543	0.563	0.51
Mean	0.46	0.469	0.47	0.490	0.502	0.512	0.523	0.528	0.539	0.55	0.565	

APPENDIX C3

Table C3 Effect of storage period on pH of dehydrated samples

Combinations	pH											
	Storage period (months)											
	0	1	2	3	4	5	6	7	8	9	10	Mean
Control	5.63	5.58	5.47	5.39	5.36	5.27	5.2	5.13	5.1	5.06	5.05	5.29
L1T1	6.83	6.52	6.48	6.42	6.39	6.02	5.96	5.89	5.72	5.64	5.53	6.12
L1T2	6.78	6.6	6.45	6.26	6.19	5.98	5.75	5.53	5.21	5.05	4.89	5.88
L1T3	6.93	6.68	6.58	6.46	5.32	5.26	5.23	5.19	5.17	5.16	5.07	5.73
L2T1	6.82	6.76	6.53	6.39	6.17	5.92	5.78	5.52	5.21	5.1	4.97	5.92
L2T2	5.62	5.36	5.22	5.14	5.13	5.14	5.09	5.02	4.97	4.8	4.75	5.11
L2T3	6.85	6.65	6.42	6.18	6.06	5.85	5.69	5.39	5.26	5.24	5.18	5.88
L3T1	6.97	6.9	6.82	6.32	6.29	6.03	5.98	5.8	5.79	5.68	5.45	6.18
L3T2	6.77	6.43	6.37	6.23	6.13	6.05	5.86	5.35	5.22	5.12	5.06	5.87
L3T3	5.89	5.59	5.42	5.41	5.28	5.19	5.08	4.98	4.89	4.81	4.78	5.21
Mean	6.509	6.307	6.176	6.02	5.832	5.671	5.562	5.38	5.254	5.166	5.073	

APPENDIX C4

Table C4 Effect of storage period on vitamin C of dehydrated samples

Combinations	Vitamin C											
	Storage period (months)											
	0	1	2	3	4	5	6	7	8	9	10	Mean
Control	10.48	10.26	10.12	9.82	9.37	8.96	8.34	8.07	7.78	7.35	7.03	8.87
L1T1	8.81	8.76	8.71	8.62	8.57	8.52	8.43	8.41	8.36	8.2	8.1	8.49
L1T2	8.4	8.37	8.29	8.2	8.12	7.88	7.65	7.44	7.32	7.21	7.17	7.82
L1T3	7.6	7.54	7.52	7.35	7.29	7.25	7.36	7.28	7.15	6.97	6.48	7.25
L2T1	10.38	10.21	10.17	10.06	9.78	9.56	9.48	9.12	8.68	8.45	8.15	9.45
L2T2	9.8	9.74	9.56	8.97	8.36	8.15	7.97	7.48	7.15	7.02	6.87	8.27
L2T3	8.7	8.68	8.63	8.45	8.38	8.31	8.29	8.21	7.48	7.14	6.37	8.05
L3T1	9.8	9.68	9.27	9.12	8.82	8.51	8.34	8.14	7.89	7.52	7.31	8.58
L3T2	8.56	8.48	8.45	8.28	7.56	7.14	6.97	6.58	6.48	6.15	5.87	7.32
L3T3	8.51	8.35	8.15	7.89	7.68	7.45	7.15	6.98	6.48	6.14	5.78	7.32
Mean	9.104	9.007	8.887	8.676	8.393	8.173	7.998	7.771	7.477	7.215	6.913	

APPENDIX C5

Table C5 Effect of storage period on total soluble solids of dehydrated samples

Combinations	Total soluble solids											
	Storage period (months)											
	0	1	2	3	4	5	6	7	8	9	10	Mean
Control	8.57	9.54	10.12	10.89	11.36	11.89	12.23	12.56	13.47	13.78	14.07	11.68
L1T1	9.25	9.52	9.86	10.23	10.56	11.57	11.86	12.45	12.84	13.33	13.89	11.39
L1T2	10.48	11.56	11.96	12.38	12.82	13.31	13.63	13.89	14.26	14.47	14.82	13.05
L1T3	9.55	9.89	10.26	10.79	11.36	11.82	12.25	12.8	12.96	13.32	13.78	11.70
L2T1	10.25	10.72	10.96	11.26	11.45	11.76	12.63	12.96	13.49	13.72	14.13	12.12
L2T2	9.44	9.78	10.36	10.87	11.36	11.77	12.56	12.87	13.35	13.78	14.26	11.85
L2T3	12.3	12.64	12.74	12.85	13.16	13.36	13.69	13.81	14.13	14.34	14.67	13.42
L3T1	7.93	8.34	8.76	9.12	9.56	9.78	10.36	10.78	11.29	11.61	12.31	9.98
L3T2	9.98	10.37	10.95	11.42	11.77	12.26	12.55	12.78	13.21	13.48	13.63	12.03
L3T3	8.36	8.85	9.15	9.67	10.26	10.85	11.45	11.77	12.31	12.62	12.97	10.75
Mean	9.61	10.12	10.51	10.94	11.36	11.8	12.32	12.66	13.13	13.44	13.85	

APPENDIX C6

Table C6 Effect of storage period on firmness of dehydrated samples

Combinations	Firmness (N)											
	Storage period (months)											
	0	1	2	3	4	5	6	7	8	9	10	Mean
Control	32.77	31.66	31.42	30.15	29.72	29.31	28.77	28.37	27.1	26.9	26.56	29.33
L1T1	42.06	41.89	41.26	40.86	40.38	39.87	39.15	38.63	38.11	37.56	36.85	39.69
L1T2	44.55	43.89	42.68	42.1	41.86	39.21	38.45	38.16	37.56	36.85	35.28	40.05
L1T3	54.31	53.78	53.12	52.78	52.26	51.85	50.47	49.24	48.52	47.14	46.24	50.88
L2T1	41.66	39.24	38.54	36.54	36.12	35.45	35.26	34.85	34.21	33.44	32.78	36.19
L2T2	45.56	44.75	43.37	42.45	42.1	41.86	41.62	40.89	39.78	37.48	36.71	41.50
L2T3	50.15	49.35	48.75	48.12	47.75	46.85	45.17	44.41	43.18	42.74	41.51	46.18
L3T1	41.87	40.85	41.33	41.1	40.89	40.27	39.74	39.25	38.47	38.24	37.74	39.97
L3T2	43.26	42.12	41.78	40.34	40.16	39.78	38.47	37.85	37.12	36.48	36.12	39.40
L3T3	50.58	49.71	48.47	47.12	46.36	45.97	44.78	43.42	42.74	41.56	40.15	45.53
Mean	44.67	43.72	43.07	42.15	41.76	41.04	40.188	39.50	38.67	37.83	36.99	

APPENDIX C7

Table C7 Effect of storage period on Rehydration ratio of dehydrated samples

Combinations	Rehydration ratio											
	Storage period (months)											
	0	1	2	3	4	5	6	7	8	9	10	Mean
Control	1.702	1.623	1.597	1.483	1.35	1.205	1.128	1.065	0.928	0.816	0.725	1.238
L1T1	1.913	1.853	1.716	1.678	1.532	1.416	1.309	1.216	1.012	0.923	0.842	1.400
L1T2	1.978	1.904	1.816	1.697	1.585	1.456	1.361	1.27	1.115	1.045	0.978	1.473
L1T3	2.041	1.932	1.831	1.692	1.596	1.489	1.416	1.36	1.294	1.191	1.012	1.532
L2T1	1.889	1.735	1.619	1.506	1.431	1.372	1.293	1.187	1.096	0.971	0.825	1.356
L2T2	1.936	1.829	1.734	1.613	1.529	1.407	1.313	1.207	1.118	1.083	0.911	1.425
L2T3	1.942	1.803	1.692	1.596	1.569	1.448	1.342	1.259	1.148	1.095	0.992	1.444
L3T1	1.709	1.636	1.596	1.513	1.429	1.347	1.291	1.155	1.013	0.931	0.896	1.319
L3T2	1.726	1.658	1.612	1.526	1.47	1.352	1.288	1.189	1.094	0.986	0.864	1.342
L3T3	1.896	1.733	1.698	1.612	1.575	1.489	1.349	1.273	1.156	1.097	0.945	1.438
Mean	1.873	1.770	1.691	1.591	1.506	1.398	1.309	1.218	1.097	1.013	0.899	

APPENDIX C8

Table C8 Effect of storage period on L* value of dehydrated samples

Combinations	L* value											
	Storage period (months)											
	0	1	2	3	4	5	6	7	8	9	10	Mean
Control	81.26	80.78	80.56	80.28	79.94	79.69	79.12	78.86	78.58	78.29	77.85	79.56
L1T1	83.3	83.23	82.83	82.59	82.26	81.84	81.62	81.46	81.2	80.95	80.62	81.99
L1T2	82.81	82.59	82.32	82.13	81.81	81.53	81.39	80.98	80.75	80.56	80.19	81.55
L1T3	81.79	81.34	81.13	80.86	80.51	80.36	80.17	79.91	79.36	79.06	78.82	80.30
L2T1	84.62	84.36	84.17	83.89	83.36	83.18	82.94	82.71	82.23	81.84	81.56	83.16
L2T2	83.55	83.37	83.07	82.82	82.67	82.31	82.08	81.98	81.62	81.36	80.93	82.34
L2T3	82.36	82.1	81.83	81.62	81.34	81.11	80.89	80.54	80.12	79.83	79.25	80.99
L3T1	84.28	83.94	83.51	82.95	82.38	82.12	81.78	81.39	80.94	80.45	79.75	82.13
L3T2	84.15	83.37	83.09	82.75	82.38	81.83	81.56	80.26	79.83	79.58	79.12	81.62
L3T3	81.62	81.39	80.92	80.64	80.12	79.98	79.55	79.27	78.94	78.65	78.28	79.94
Mean	83.12	82.78	82.50	82.21	81.85	81.55	81.283	80.89	80.51	80.21	79.78	

APPENDIX C9

Table C9 Effect of storage period on a* value of dehydrated samples

Combinations	a* value											
	Storage period (months)											
	0	1	2	3	4	5	6	7	8	9	10	Mean
Control	1.72	1.86	1.98	2.08	2.2	2.36	2.53	2.73	2.96	3.16	3.45	2.457
L1T1	0.07	0.09	0.13	0.28	0.43	0.62	0.92	1.24	1.41	1.63	1.89	0.791
L1T2	0.11	0.21	0.39	0.53	0.89	1.01	1.25	1.57	1.68	1.82	1.98	1.04
L1T3	0.31	0.48	0.79	0.97	1.16	1.32	1.56	1.83	1.98	2.19	2.38	1.360
L2T1	0.09	0.19	0.26	0.59	0.97	1.16	1.25	1.29	1.44	1.46	1.54	0.930
L2T2	0.28	0.36	0.48	0.72	0.97	1.28	1.59	1.83	1.97	2.01	2.12	1.237
L2T3	0.54	0.72	0.81	1.01	1.19	1.26	1.43	1.69	1.96	2.13	2.39	1.375
L3T1	0.36	0.51	0.62	0.78	0.91	1.02	1.15	1.26	1.39	1.46	1.56	1.001
L3T2	0.41	0.53	0.69	0.81	0.93	1.09	1.21	1.32	1.43	1.53	1.62	1.051
L3T3	0.493	0.61	0.67	0.82	0.99	1.16	1.25	1.46	1.58	1.71	1.96	1.154
Mean	0.438	0.556	0.682	0.859	1.064	1.228	1.414	1.622	1.78	1.91	2.089	

APPENDIX C10

Table C10 Effect of storage period on b* value of dehydrated samples

Combinations	b* value											
	Storage period (months)											
	0	1	2	3	4	5	6	7	8	9	10	Mean
Control	26.89	26.56	25.4	24.37	24.12	23.89	22.4	22.29	21.96	21.68	21.34	23.71
L1T1	35.85	34.92	33.56	32.19	31.52	30.82	30.13	29.72	29.12	28.89	28.67	31.39
L1T2	36.19	35.81	35.47	35.01	34.77	34.29	33.78	33.5	32.72	32.19	31.86	34.14
L1T3	32.73	32.36	31.91	31.48	30.15	29.94	29.76	29.36	28.89	28.38	27.39	30.21
L2T1	34.92	34.77	34.02	33.89	33.28	32.71	31.02	30.84	30.13	29.86	28.16	32.14
L2T2	37.48	37.16	36.86	36.19	35.75	34.42	33.74	33.12	32.76	31.84	30.43	34.52
L2T3	36.72	33.78	32.84	32.19	31.86	30.92	30.47	29.98	29.15	29.75	28.72	31.48
L3T1	31.62	30.96	30.04	29.84	28.36	28.15	28.02	27.51	27.18	26.56	26.45	28.60
L3T2	35.04	34.89	34.09	33.51	32.42	31.74	31.08	31	29.86	29.15	29.06	31.98
L3T3	38.67	37.48	36.68	35.82	34.05	33.51	32.41	31.83	31.36	30.56	29.58	33.81
Mean	34.61	33.86	33.08	32.44	31.62	31.03	30.28	29.91	29.31	28.88	28.16	

APPENDIX C11

Table C11 Effect of storage period on ΔE value of dehydrated samples

Combinations	ΔE value										
	Storage period (months)										
	1	2	3	4	5	6	7	8	9	10	Mean
Control	0.599	1.666	2.727	3.105	3.44	5.03	5.28	5.746	6.167	6.739	4.052
L1T1	1.714	2.515	3.75	4.370	5.06	5.78	6.24	6.887	7.181	7.498	5.101
L1T2	0.450	0.914	1.42	1.903	2.41	3.02	3.56	4.330	4.897	5.395	2.836
L1T3	2.001	2.368	2.81	3.893	4.17	4.49	5.01	5.749	6.35	7.271	4.414
L2T1	2.008	2.025	1.91	2.112	2.58	4.10	4.26	4.978	5.267	6.959	3.622
L2T2	0.375	0.809	1.54	2.059	3.44	4.22	4.88	5.372	6.292	7.742	3.676
L2T3	3.876	4.786	5.45	5.899	6.81	7.33	7.96	8.920	8.605	9.811	6.946
L3T1	2.416	2.477	2.26	3.392	3.56	3.68	4.21	4.608	5.308	5.616	3.755
L3T2	0.803	1.450	2.11	3.204	4.09	4.79	5.68	6.821	7.53	7.907	4.440
L3T3	3.127	3.909	4.63	6.236	6.74	7.88	8.53	9.117	9.947	10.99	7.112
Mean	1.737	2.292	2.86	3.617	4.24	5.03	5.56	6.253	6.756	7.593	

APPENDIX C12

Table C12 Multi response optimization constraints of experiment

Sl. No.	Parameters	Goal	Lower limit	Upper limit
1	Moisture content	minimize	4.73	11.606
2	Water activity	minimize	0.425	0.621
3	pH	In range	4.54	7.17
4	Vitamin – C	maximize	5.606	10.794
5	Firmness	minimize	26.95	55.93
6	Total soluble solids	maximize	7.77	15.26
7	L* value	maximize	73.957	87.536
8	a* value	minimize	0.067	3.588
9	b* value	maximize	20.273	40.21
10	Rehydration ratio	minimize	0.688	2.102

APPENDIX C13

Table C13 Sensory evaluation of dehydrated jackfruit slices during storage

Sensory qualities	Combinations			
	Control	L1T2	L2T1	L2T2
Colour and appearance	5.95	7.81	7.9	6.7
Taste	7	6.45	7.27	6.59
Flavour	6.5	6.5	6.7	6.7
Texture	6.86	6.13	7.31	6.6
Overall acceptability	6.59	6.4	7.77	6.86

APPENDIX D

Cost economics of developed blancher cum dryer for dehydrated jackfruit slices

Estimation of cost of production for dehydrated jackfruit slices

Cost of machineries		
Cost of Blancher cum dryer	=	Rs.2,00,000/-
Cost of jackfruit corer cum cutter	=	Rs.34,500/-
Cost of jackfruit slicer	=	Rs.50,000/-
Miscellaneous item	=	Rs.20,000/-
Building cost (100 m^2)	=	Rs.20,00,000/-
Total cost	=	Rs.23,04,500/-

Assumptions

Life span (L)	=	10 years
Annual working hours (H)	=	275days (per day 8 hrs) = 2200 hours
Salvage value (S)	=	10% of initial cost
Interest on initial cost (i)	=	15% annually
Repair and maintenance	=	10% of initial cost
Insurance and taxes	=	2% of initial cost
Electricity charge	=	Rs.7/unit
Labour wages/person	=	Rs.500/day

1. Total fixed cost		
i. Depreciation	=	$\frac{C - S}{L \times H} =$ $\frac{23,04,500 - 2,30,450}{10 \times 2200}$ =Rs.94.275/h
ii. Interest	=	$\frac{C + S}{2} \times \frac{i}{H}$ $\frac{23,04,500 + 2,30,450}{2} \times \frac{15}{100 \times 2200}$ = Rs.86.41/h
iii. Insurance & taxes	=	2% of initial cost $\frac{2}{100 \times 2200} \times 23,04,500$ = Rs.20.95/h
Total fixed cost	=	i + ii + iii = 201.63/h
2. Total variable cost		
i. Repair & maintenance		10% of initial cost $= \frac{10}{100 \times 2200} \times 23,04,500$ =Rs.104.75/h
ii. Electricity cost		
a)Energy consumed by the blancher cum dryer Steam generator Dryer	= =	5 kWh 6.12 kWh

Cost of energy consumption/h Drying Steam generator	 = 	Power × duration × cost of 1 unit = 6.12 × 8 × 7 = Rs.342.72/day = 5× 0.5 × 7 = Rs.17.5/day
b) Energy consumed by the slicer and corer	=	0.36 + 0.0149 0.374 kWh
Cost of energy consumption/h	=	0.374 × 1 × 7 Rs.2.61/day
iii. Labour cost (2 person)	=	Rs.1000/day
iv. Packaging cost	=	Rs 100/day
v. Cost of raw materials for preparation of dehydrated jackfruit slices		
Quantity of Jackfruit required Average weight of one jackfruit Average pulp from 22 kg jackfruit (excluding wastage) Unit rate of matured jackfruit Total cost of the jackfruit Preservatives Total cost of the materials	= = = = = = =	1100 kg 22 kg 8kg Rs.10/kg 10×1100 =Rs.11,000 Rs.3000 3000+11000 = Rs.14000
Therefore variable cost(dehydrated chips)	=	i + ii + iii + iv + iv Rs.15,567.58/-
Therefore total cost for production of 100 kg of dehydrated jackfruit slices	=	Fixed cost + Variable cost 1613.04+ 15,567.58/- = 17,180.6/100 kg of dehydrated slices = 172/kg of dehydrated slices

The market selling price of 1kg of dehydrated slices = Rs.520/kg

$$\text{Benefit -cost ratio} = \frac{800}{172} = 4.65$$

Therefore the total production cost of 1kg of dehydrated slices in blancher cum dryer was found to be Rs.172/-.The benefit cost ratio was found to be 4.65:1

APPENDIX E

Cost economics of existed cabinet tray dryer for dehydrated jackfruit slices

Estimation of cost of production for dehydrated jackfruit slices

Cost of machineries		
Cost of cabinet tray dryer	=	Rs.1,50,000/-
Cost of steam blancher	=	Rs.68,700/-
Cost of jackfruit corer cum cutter	=	Rs.34,500/-
Cost of jackfruit slicer	=	Rs.50,000/-
Miscellaneous item	=	Rs.20,000/-
Building cost (additional requirement $5m^2$) $105m^2$		Rs.21,00,000/-
Total cost	=	Rs.24,23,200 /-

Assumptions

Life span (L)	=	10 years
Annual working hours (H)	=	275days (per day 8 hrs) = 2200 hours
Salvage value (S)	=	10% of initial cost
Interest on initial cost (i)	=	15% annually
Repair and maintenance	=	10% of initial cost
Insurance and taxes	=	2% of initial cost
Electricity charge	=	Rs.7/unit
Labour wages/person	=	Rs 500/day

3. Total fixed cost		
i. Depreciation	=	$\frac{C-S}{L \times H} = \frac{24,23,200 - 2,42,320}{10 \times 2200} =$ Rs.99.13/h
ii. Interest	=	$\frac{C+S}{2} \times \frac{i}{H}$ $\frac{24,23,200 + 2,42,320}{2} \times \frac{15}{100 \times 2200}$ = Rs.90.87/h
iii. Insurance & taxes	=	2% of initial cost $\frac{2}{100 \times 2200} \times 2423200$ = Rs.22.02/h
Total fixed cost	=	i + ii + iii = 212.02/h
Total variable cost		
i. Repair & maintenance		10% of initial cost $= \frac{10}{100 \times 2200} \times 2423200$ = Rs 110.14/h
ii. Electricity cost		

a)Energy consumed by the cabinet tray dryer Steam blancher Dryer	 = =	 1.87 kwh 10.74kwh
Cost of energy consumption/h Drying Steam blancher	 =	Power × duration × cost of 1 unit = 10.7 × 8 × 7 = Rs.599.2/day = 1.87× 3 × 7 = Rs.39.27/day
b) Energy consumed by the slicer and corer	=	0.36+0.0149 0.374 kwh
Cost of energy consumption/h	=	0.374 × 1 × 7 Rs.2.61/day
iii. Labour cost (2 persons)	=	Rs.1500/day
iv. Packaging cost	=	Rs 100/day
v. Cost of raw materials for preparation of dehydrated jackfruit slices		
Quantity of Jackfruit required Average weight of one jackfruit Average pulp from 22 kg jackfruit (excluding wastage) Unit rate of matured jackfruit Total cost of the jackfruit Preservatives	= = = = = =	1100 kg 22 kg 8kg Rs.10/kg 10×1100 =Rs.11,000 Rs.3000

Total cost of the materials	=	=3000+11000 = Rs.14000
Therefore variable cost(dehydrated chips)	=	i + ii + iii + iv + iv Rs.16,351.22/-
Therefore total cost for production of 100 kg of dehydrated jackfruit slices	=	Fixed cost + Variable cost 1696.16 + 16351.22 = 18,047/100 kg of dehydrated slices = 180/kg of dehydrated slices

The market selling price of 1kg of dehydrated slices = Rs.520/kg

Benefit -cost ratio $= \frac{800}{180} = 4.43$ Therefore the total production cost of 1kg of dehydrated slices in cabinet tray dryer was found to be Rs.180/-. The benefit cost ratio was found to be 4.43:1.

APPENDIX F

SENSORY SCORE CARD FOR FRIED JACKFRUIT SLICES

Name of judge:

You are requested to assess the product in terms of general acceptability on a 9 point hedonic scale.

Score system:

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

Characteristics	Sample code					
	A	B	C	D	E	F
Colour & appearance						
Texture						
Flavor						
Taste						
Overall acceptability						

Comments if any: Signature

DEVELOPMENT AND PERFORMANCE EVALUATION OF A BLANCHER CUM DRYER FOR JACKFRUIT

by

ANUPAMA B. M.
(2015-18-007)

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the

requirement for the degree of

MASTER OF TECHNOLOGY

IN

AGRICULTURAL ENGINEERING

(Agricultural Processing and Food Engineering)

Faculty of Agricultural Engineering & Technology

Kerala Agricultural University

DEPARTMENT OF FOOD AND AGRICULTURAL PROCESS ENGINEERING
KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
TAVANUR - 679573, MALAPPURAM
KERALA, INDIA

2017

Abstract

Jackfruit is an indigenous and underutilised tropical fruit rich in nutrients. It can be consumed as both fruit in the ripe and as vegetable in the unripe stage. Jackfruit is a seasonal crop as to ensure its year round availability, appropriate processing protocols are to be standardised to develop quality products. Dehydration is one of the most widely used preservative methods to increase the shelf life of the product. Steam blanching along with preservatives is essential step to accelerate the drying rate and to prevent quality deterioration. In the traditional jackfruit drying process protocol, separate drying and blanching were utilised which increased both the production and as well as occupied more plant space. In this scenario there is a great demand for the development of a blancher cum dryer for jackfruit. In the present study blancher cum dryer with a volume of 2.052 m^3 and capacity was fabricated and evaluated at different loading rate. Blanching time of 7 min and preservatives (0.2% citric acid, 0.1% KMS and 0.5% turmeric powder) were standardised based on enzyme inactivation, texture and colour retention. Slices were dried in three different drying temperatures (60, 65 and 70°C) at various loadings (L1 (3.8), L2 (4.8) and L3 (5.8) kg/m^2. Dehydrated slices were packed in LDPE 100 µm bags and kept for storage studies at ambient atmospheric condition for a period of ten months. Quality analysis *viz.*, moisture content, water activity, TSS, pH, vitamin C, texture, colour and microbial analysis were carried out at every one month storage interval. At the end of storage period best quality and microbiologically safe samples were selected for the sensory evaluation. Based on the sensory qualities maximum overall score was obtained for L2T1 (loading capacity 23 kg at 60°C) combination and hence was selected. Developed machine was compared with the existing model in terms of loading capacity, power and time consumption, labour cost, fabrication cost and quality of the dehydrated samples. The overall cost for the development of blancher cum dryer was Rs.2,00,000/-. The total production cost of one kg dehydrated jackfruit slices in blancher cum dryer and existing model were Rs.172/- and 180/- respectively.