OPTIMIZATION OF PROCESS PARAMETERS FOR VACUUM DRYING OF RIPE JACKFRUIT BULB (*Artocarpus heterophyllus L.*)

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By

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Department of Food and Agricultural Process Engineering

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679573, MALAPPURAM

2015

DECLARATION

I, hereby declare that this thesis entitled **"Optimization of Process Parameters for Vacuum Drying of Ripe Jackfruit bulb (*Artocarpus heterophyllus L.*)"** is a bonafide record of research done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled **"Optimization of Process parameters for Vacuum Drying of Ripe Jackfruit bulb (*Artocarpus heterophyllus L.*)"** is a record of research work done independently by **Mrs. Padmavathi.D (2013-18-108)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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Padmavathi.D

Dedicated to

Food processing

Profession

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INTRODUCTION

CHAPTER 1

INTRODUCTION

Fruits and vegetables have historically held a place in dietary guidance because of their concentrations of vitamins (mainly vitamins C and A), minerals (particularly electrolytes) and phytochemical (especially antioxidants). Additionally, fruits and vegetables are recommended as a source of dietary fiber (Slavna *et al*., 2012). In the recent years, demand for both fresh and processed fruits and vegetables have been substantial and this trend is likely to continue in future. Fruits and vegetables are the important source of energy for human-beings. Fruit and vegetable consumption has been linked to reduced cardiovascular diseases, stroke, digestive disorders, hypertension and cancer. The increasing demand can be regulated by either increasing their production or by adapting suitable techniques to enhance the shelf life.

Even though, India is the largest producer of fruits and vegetables after China, it processes only less than 2.5% of the production as compared to 70-83% in advanced countries (Akhila and Shareena, 2009). As per National Horticulture Database published by National Horticulture Board, during 2012-13, India produced 81.285 million metric tonnes of fruits and 162.19 million metric tonnes of vegetables. The area under cultivation of fruits stood at 6.98 million hectares while vegetables were cultivated at 9.21 million hectares. The country has exported 2, 87,384.63 MT of processed fruits and vegetables worth Rs. 2,266.66 crores during the year 2013-14. Ministry of Food Processing Industries (2009) reported that about 35% of the total production of fruits and vegetables in India are lost due to improper processing and storage. This loss is mainly because of highly perishable nature of these commodities and also due to mechanical injury and pathological breakdown. This results in changes in texture and nutritional value of the food which results the food unpalatable and potentially unsafe for human consumption.

Technological development and intensification of underutilized crops is most important to fill the ever increasing demand-supply gap. Jackfruit

(*Artocarpus heterophyllus L.*) is a tropical fruit from the family Moraceae, genus Artocarpus, is an exotic tree originally native to the Western Ghats of India. The name jack is said to be an adoption of Portugese word 'Jaca' which in turn is believed to have originated from Malayalam name of the fruit, 'Chakka'. The other Indian names of ths fruit are: Halasu (Kannada), Panasa (Sanskrit and Telgu), Kathal (Hindi), Phanas (Marathi) and Pala (Tamil), (Pradeepkumar and Kumar, 2008). In Asia-pacific, India is the largest producer followed by Bangladesh and Thailand. (Kittur *et al.,* 2015). In India, it is grown in southern and eastern states viz., Kerala, Karnataka, Tamilnadu, Goa, coastal Maharashtra and other states like, Assam, Bihar, Tripura, Uttar Pradesh and foothills of Himalayas.

In Kerala, jackfruit which is an under exploited fruit cultivated as a homestead tree without any management practices and is identified as an organic fruit. The major classifications of this fruit in Kerala are 'Koozha Chakka' and 'Varikka Chakka'. The former jackfruit has small, fibrous, soft, mushy, but very sweet carpel whereas the latter is more important commercially, with crisp carpel of high quality. It is commonly referred to as poor man's fruit (Rahman *et al.*, 1995). Jackfruit is rich in Vitamin A, B, C and minerals such as calcium and iron (Crane *et al.*, 2005). It is having immense medicinal value and is considered a rich source of carbohydrates, minerals, carboxylic acids, dietary fiber and vitamins such as ascorbic acid and thiamine (Lin *et al*., 2000). Also, the fruit contains free sugar (sucrose), fatty acids, ellagic acid and amino acids like arginine, cystine, histidine, leucine, lysine, metheonine, theonine, tryptophan etc. (Swami *et al*., 2012).

The fruits bulky nature and the availability of edible portion (around 35% of the whole fruit) make it difficult to transport and store. The fruit is seasonal and the post harvest losses are as high as 30%. Therefore, there is a need to develop a suitable processing protocol to reduce losses and also to enhance the shelf life to extend the availability of this precious bulb in a ready to eat form thoughout the year.

Among the many post harvest operations of agricultural products, *drying* is the most widespread and oldest method of preservation adopted thoughout the world. Besides preserving seasonal commodities by the reduction in water activity, drying also saves storage space and reduces transportation costs. (Greensmith, 1998). Drying of agricultural products is still the most widespread preservation technique, and dried fruits have become an alternative to fresh fruits because the demand for high-quality dried fruits is increasing all over the world (Esper and Muhlbauer,1996). The basic concept of drying is the removal of water down to a thesh hold value by evaporation and it involve heat and mass transfer accompanied by phase change. The drying process of fruits and vegetables are classified as solar drying, atmospheric drying and sub atmospheric dehydration which include vacuum shelf, belt, drum and freeze dryer. Dehydrated products need to be rehydrated before consumption or further processing (Oliveira and Ilincanu, 1999). During rehydration, absorption of water into the tissue results in increase in the mass. Simultaneously, leaching out of solute (sugars, acids, minerals and vitamins) also occurs and both phenomena are influenced by the nature of the product and conditions employed for rehydration (Lewicki, 1998).

Vacuum drying of food is relatively new technique which is widely used to dry various heat-sensitive products in which the colour, structure, and vitamins are impaired with increasing temperatures (Methakhup *et al.,* 2005). Rather than freezing food to low temperatures, the air around the food is removed. This causes rapid evaporation of water inside food. The processing speed and method preserves the taste, color and nutritional value of the food. Since the fibers are fully preserved, vacuum dried fruit will reproduce the original texture of fresh fruit while reconstitution with water. Some dried fruits and vegetables are not ready to eat since they require rehydrating before they can be used in cooking; but the properties of rehydrated products are poor.

Pre-treatment prevents the loss of colour by inactivating enzymes and reduce the drying time by yielding a good quality dried product (Kingsly *et al*., 2007). Blanching is one of the pre-treatment that are used to arrest the physiological processes before drying. Generally, fruits and vegetables are blanched by heating them with steam or hot water (Mate *et al*., 1998; Tembo *et al*., 2008)

Steam blanching is 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 is reduced compared to water blanching (John *et al.*, 2004) and blanching along with citric acid was used to reduce the drying time and color losses (Fellows, 2000; Doymaz, 2010).

Keeping the above cited facts the present study was conducted with the following objectives.

- To standardize the blanching treatments for ripened deseeded jackfruit bulb.
- To optimize the vacuum drying parameters for ripened deseeded jackfruit bulb.
- Packaging and storage studies of vacuum dried ripened deseeded jackfruit bulb in terms of nutritional and quality attributes.

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

This chapter gives the general information on jackfruit, its physical and chemical composition, blanching characteristics, drying, packaging methods and its storage studies. Research done on these aspects are also reviewed and discussed in detail.

2.1 JACKFRUIT (*ARTOCARPUS HETEROPHYLLUS* L.)

2.1.1 History and distribution

Jackfruit (*Artocarpus heterophyllus*) is believed to originate from Western Ghats, India. India is the second biggest producer of the fruit in the world and is considered as the motherland of jackfruit. In India, the total area under jackfruit cultivation is approximately 1,02,552 hectares, of which, an estimated 1,00,000 trees are grown in back yards and as intercrop in other commercial crops. Kerala has the largest area of jackfruit cultivation of about 97,540 ha and production around 348 million tons (APAARI. 2012). Jackfruit is widely grown as an important tree in Kerala’s homesteads.

Sharma *et al*., (1997) reported that jackfruit tree is attractive large tree which has glossy, dark green and shiny leaves which can produce a very large, oval shaped fruit. Jackfruits mature 3 to 8 months from flowering. When mature, there is usually a change of fruit colour from light green to yellow-brown. After ripening, they turn brown and deteriorate rather quickly. Yield varies from a few fruits during first year of bearing and it may be as high as 250 fruits after 15 years of age. The edible portion in the form of bulbs after pitting is approximately 30–35% of the whole fruit (Alok *et al*., 2009)

2.1.2 Propagation

Haq (2006) claimed that jackfruit is a highly cross pollinated crop and plants raised from seed never bear fruits true to the type of the mother plant. But the most common method of propagation is by seed which is easy and cost effective method. Germination starts within 10 days after the seeds are sown and 100% seeds germinate within 35-40 days. After germination, the most vigorous seedlings are retained and the weaker ones are removed. The seed viability is only 14 days, so it should be sown immediately after the extraction. The seedlings can also be raised in pots or poly bags. After one or two years, the seedlings are planted in the field. Vegetative propagation is a new technique produces a plant which is genetically identical to the mother plant. The most common vegetative propagation methods include: cuttings, layering and air layering, budding and grafting onto seedling rootstocks and in vitro tissue culture.

2.1.3 Varieties

According to Elevitch and Manner (2006) the variation in species is based on tree size and structure, leaf and fruit form, age of fruit bearing, fruit size, shape, and color and texture of the edible pulp. In Kerala, Jackfruit can be categorized into 2 major types, based on the quality of the pulp. The first type is *koozha chakka* the fruits are fibrous, thin, soft and musky; can range from sour to very sweet and emits a strong aroma when ripe. The second type is *Varikk*a which has thick edible pulp, firm and crisp and less odorous. The second type is more commercially accepted.

2.1.4 Harvesting

Kader and Watkins (2000) claimed that jackfruit must be harvested at the right stage of maturity. Optimum maturity for jackfruit ranges between 12 and 16 weeks after flower anthesis, depending on the clone. Fruit is considered mature to harvest when the leaf on the stem wilts and the fruit green colour changes to green yellowish.

Ong *et al*., (2006) studied that chemical composition (titrable acidity, moisture content, crude fiber, colour, pH, soluble solids, sugars, and organic acids) and flavor changes during ripening of jackfruit and were optimum after five days of harvest

2.1.5 Post Harvest Utility

Narasimham (1990) stated that mature jackfruits are cooked as vegetables, either in curries or salad. Ripe fruits can be eaten raw, or cooked in creamy coconut milk as dessert, made into candied jackfruit or jackfruit leather.

Roy and Joshi, (1995) remarked that, In India, jackfruit seeds are also eaten as such or boiled in sugar and eaten as dessert. In Malaysia, the seeds are boiled with a little salt. Dried seeds were also used to make flour for value-added products. The unfertilized fruits can also be used with/or to replace fruit pulps.

According to Nakasone and Paul (1998) jackfruit is also used for further processing. For instance, jackfruit leather and jackfruit chips, made from dried jackfruit pulps (Nakasone and Paull, 1998).

Roy and Joshi (1995) also stated that pureed jackfruit is also developed into baby food, juice, jam, jellies and base for cordials Jackfruits are made into candies, fruit-roll, marmalades and ice cream. Other than canning, advances in processing technologies too, have pushed towards more new products (Narasimham, 1990).

Ukkuru and Pandey (2005) have developed ready to-eat fresh jackfruit bulbs along with seeds which were preserved under vacuum (760 mm lbs pressure) by treating with 1.5% KMS and 0.5% sodium benzoate.

Jackfruits for export market are usually in “whole-fruit” forms. The high freight cost of bulk fruits of which only about 40% of the fruits are edible are not cost-effective for local farmers. Hence, new developments in processing of jackfruit, especially to ensure suitable shelf life for export purposes are very important.

2.1.6 Nutritional composition

Narasimham (1990) proposed that jackfruit is a good source of carbohydrate, vitamin A and a fair protein source. The jackfruit pulps contain quite high amount of carbohydrates, fiber, potassium and carotene. The nutrient composition and nutritive values of fresh jackfruit is presented in Appendix I.

Jagadeesh *et al.*, (2007) studied about the chemical composition of bulbs from 24 different firm-type jackfruit clones was analyzed to study the variability. A wide variation in the total soluble solid (TSS), acidity, TSS: acid ratio, sugars, starch and carotenoid contents was observed in the bulbs of jackfruit types considered in the present investigation. The results of the study are helpful for attempting crop improvement and selection of superior desirable jackfruit genotypes for bringing to cultivation. Also it is a nutritious fruit, rich in vitamins A, B and C, potassium, calcium, iron, proteins and carbohydrates. Due to high levels of carbohydrates, jackfruit supplements other staple foods in times of scarcity in some regions.

2.2 PRE-TREATMENT STUDIES

Salunkhe *et al*., (1991) reported that pre-treatment methods and drying may contribute to the deterioration of both eating quality and the nutritive value of a food product. Pre-treatments are the necessary pre-requisites for successful dehydration process. Pre-treatments check the undesirable physical, chemical and qualitative changes that may occur during the drying process. Pretreatments such as blanching were given to reduce the rate of biochemical and microbiological changes, brighten the colour and increase shelf life of the product. Fruit has to be pretreated in some way before the main drying treatment. Purpose of this unit operation is to facilitate and accelerate the main treatment. Common pretreatments in food industry are washing, peeling and slicing, dipping into alkaline or acid solutions, sulphuring or sulphating, blanching, different dehydration processes and others.

2.2.1 Blanching

Over the years, (Taylor *et al.,* 1981; Canet and Hill 1987) reported that low-temperature long time blanching is better compared to the conventional high-temperature short-time blanching for quality retention. Low-temperature longtime blanching, in comparison to high temperature short time, enhances the firmness and reduces the nutritional and flavor losses of the product

According to Rahman and Perera (1999) blanching of fruits and vegetables is a common pretreatment used prior to freezing, and drying. This is done to achieve improved quality and storage ability of the finished product. The primary purpose of blanching is to inactivate naturally occurring enzymes present in food. In addition, there are other advantages for blanching depending upon the method of further processing, such as removal of gases from vegetable surfaces and intercellular spaces to prevent oxidation, discoloration, and off-flavor development as well as reducing the initial number of microorganisms.

Fellows (2000) stated that loss of carotenoids will lead to colour changes in fruits and vegetables; this phenomenon can be prevented by blanching, or treatment with ascorbic acid or sulphur dioxide.

Severini *et al.,* (2004) studied the optimization of the blanching process of sliced potatoes with respect to nutrient retention (ß-carotene, vitamin C loss) and product yield should be considered along with the inactivation of enzymes. The variables, such as temperature, time of treatment, concentration and nature of the acid or salt in the blanching solution, which determines the effectiveness of the blanching process.

Shivhare *et al*., (2009) claimed that blanching in water has the advantage of a homogenous treatment of food and the possibility of modulating the temperature of blanching. For example, the conditions of carrot blanching at a higher temperature of 95°C for 1 minute to inactivate polyphenoloxidase and peroxidase.

Gudapaty *et al*., (2010) remarked the combination of osmotic dehydration with conventional water blanching before the process of drying of Indian gooseberry and reported that drying time leads to a less degradation of vitamin C. However, the fruit segments osmotically dehydrated with salt (2%) retained a higher content of vitamin C compared to those subjected to a supplementary pretreatment by blanching process.

2.2.2 Steam blanching

Lazer (1972) explained the effect of blanching of carrots and potatoes with superheated steam followed by partial drying of food. Results showed little difference between heating with saturated steam and heating with superheated steam but selection of temperature can be less than 150^0C for carrots and potatoes because of scorching.

Saikia and Dutta (1995) developed method for increased recovery of fresh juice from ripe *Dillena* fruit by application of blanching in steam for 0,2, 3, 4, 5 and 6 minutes and reported that increase in blanching time significantly yield the juice percentage from 25 to 41.67 per cent.

Sharma *et al*. (2000) studied about different blanching (steam, water and microwave) and drying (cabinet and fluidized-bed-drying) methods on the stability and composition of total carotenoids in carrots. Total carotenoid losses were higher in un blanched carrots and in fluidized bed-dried samples compared to blanched and cabinet-dried samples. Regarding individual carotenoids, beta-carotene degraded at rapid rate, while lute in degraded at slower rate during storage. Development of non-enzymatic browning during storage was also influenced by the blanching treatments. It was concluded that steam-blanching prior to drying of carrots minimizes loss of carotenoids compared to microwave- and water-blanching.

Singh and Kulshestha (2006) remarked the effect of steam blanching on the preservation of carrot powder. The peeled and grated carrots were steam blanched for one minute and then immersed in 0.125% KMS solution for 4 minutes.

The stability of peroxidase (POD) and polyphenoloxidize (PPO) was studied in mango slices as well as the colour after different times of blanching at 94^0C with saturated steam (Ndiaye *et al*., 2009). The POD was totally inactivated after five minutes and the PPO after 7 minutes. Thee minutes of steam blanching lead to a residual activities less than 2.85% and 8.33% of PPO and POD, respectively.

Jose *et al*., (2004) claimed that steam blanching requires less time than water blanching because the heat transfer coefficient of condensing steam is greater than that of hot water but because of the high-temperature gradients between the surface and the center of the product chances of over blanching near the surface than the centre.

2.2.3 Citric acid along with blanching

Domyaz (2010) reported that dipping in 0.5% citric acid along with blanching of red apple prior to drying reduces the drying time but the rehydration ratio was higher for blanched samples.

2.3 DRYING STUDIES

According to Menon and Majumdar (1987) drying is a combination of transfer of energy and transfer of mass. Energy transfer can be conductive, convective, radiative, or any combination of these thee. Mass transfer includes the removal of moisture that moves from the interior of dried material towards object surface. All these processes must be understood and scrutinized prior to any industrial or pilot-scale laboratory application.

Venkatachapalathy (1998) reported that heat supplied from external source is transferred by some of thee heat transfer methods to the material and the vapour pressure of material moisture is increased, causing the diffusion of vapour to the surface. On the surface, vapour is taken away either with flowing air (convective drying) or by itself (vacuum drying, freeze drying).

During drying, many changes take place including structural and physico-chemical modifications which affect the final product quality (Baysal *et al.*, 2003).The removal of moisture prevents the growth and reproduction of microorganisms and minimizes many moisture-mediated deteriorative reactions. It brings about substantial reduction in weight and volume, minimizes packing, storage, transportation costs and enables storability of the product under ambient temperatures (Mujumdar and Menon, 1995).

2.3.1 Vacuum drying

Brown *et al*., (1964) explained that in vacuum drying the boiling point of water is lowered below 100^{o}C by reducing the pressure. The degree of vacuum and the temperature for drying depend on the sensitivity of the material to drying rate and temperatures. At constant temperature and pressure, the drying time varies; depending on the kind of fruit, initial moisture and size, but is generally 4 to 16 hours.

Somogyi and Luh, (1986) reported that the vacuum drying method is under the category sub atmospheric drying. Because of the high installation and operating cost, vacuum dryers are used only for high-value materials and to dry materials with low final moisture. Vacuum treatment is also useful in combination with some other processes, such as microwaves, osmotic dehydration (Argaiz *et al*., 1994), or as a finishing drying method

Potter and Hotchkiss (1995) claimed that drying at low pressure, as in vacuum drying, decreases the boiling point of water. At a constant product temperature, lower pressure can speed up the evaporation rate of water, thereby reducing the drying time. Vacuum dried products have a puffed and frothy structure because air and moisture inside the product expands due to vacuum which increases high rate of heat and mass transfer.

Moran and Shapiro, (1996) concluded that the main purpose of vacuum drying is to enable the removal of moisture at lower temperature than the boiling point under ambient condition. Water is boiling on 1 bar at 100°C, but if the pressure is lowered to 40 mbar, boiling temperature will be 28.96°C The important feature of vacuum drying is virtual absence of air during dehydration, which makes this process attractive for drying of material that may deteriorate and/or be chemically modified as a result to air or high temperature exposure.

Youngsawastidigul and Gunasekaran (1996) studied about microwave-vacuum drying of cranberries. The experiment was done both in the pulsed and continuous modes. The dried products were redder and had a softer texture than those dried by the conventional hot-air method.

Markowski and Bialobrzewski (1997) studied the drying kinetics of celery slice (10 mm thick, 57 mm diameter) using air drying in vacuum chamber. Experiments were carried out at temperatures of 25 to 50°C and pressure inside the chamber was maintained at 10+0.2 kPa. The drying rate versus product water content curves showed no constant drying rate period in all cases. The amount of water absorbed by celery slice previously dried with a vacuum drier was measured. The samples dried at lower temperature level absorbed more water than those dried at higher temperatures. The results proved that vacuum drying could be used for preservation of high quality celery slices in terms of color and flavor.

Kiranoudis *et al*., (1997) examined the drying kinetics of apples, kiwi fruits and pears by introducing a one-parameter empirical mass transfer model; the model was tested with data produced in a vacuum equipped with MW apparatus. The best fit of comparison was obtained with kiwi and worst with apples. It was found that the drying constant was affected with MW power and vacuum pressure, in highly positive and slightly negative manner, respectively.

Vacuum drying has been applied widely to dry various heat-sensitive products in which qualities such as color, texture and various vitamins are deteriorated at elevated temperatures (Drouzas and Schubert, 1996; Markowski and Bialobrzewski, 1997; Jaya and Das, 2003).

Drouzas *et al*., (1999) studied the combined microwave (MW)/vacuum drying of fruit materials has a promising potential for high-quality dehydrated products. A laboratory MW/vacuum drier was used for drying kinetics experiments with model fruit gels, simulating orange juice concentrate. The system was operated in the vacuum range of 30 - 50 mbar and MW power of 640 - 710 W. The distribution of the electromagnetic field in the cavity of the oven was determined from the drying rate of samples, placed at 5 different locations. The drying rate was determined by periodic weighing of the sample. The rate constant (K) of the single-layer model of drying was estimated by regression analysis of the experimental data. An empirical model is proposed for estimating the drying constant (K) as a function of the absolute pressure and the MW power of the system.

Chen and Chiu (1999) investigated the kinetics of volatile compound retention in onions. They reported that microwave vacuum drying of onion simultaneously overcame heat and mass transfer resistance with high drying rate and high volatile retention.

Drouzas *et al.,* (1999) studied about drying of pectin gels (concentrated orange juice) and declared that combination of MW heating and vacuum drying resulted in the acceleration of drying rate for model fruit gels. The experimental pectin gel with 38.4% of moisture content was dried to less than 3% of moisture in less than four minutes. However, due to the uneven distribution of the MW energy in the MW oven, the location of material in the cavity should be specified. Color of the dried gel was also better compared to air drying.

Erle and Schubert (2001) claimed that vacuum drying is the exclusion of air during drying, which makes this process more effective for drying food materials that may deteriorate or chemically modified due to air or exposure to high temperature. Vacuum drying allows water to vaporize at a lower temperature than at atmospheric pressure, and fruits are dried without exposing to high temperature. Moreover the absence of air during dehydration diminishes oxidation reactions. Because of these advantages, there is an improvement in color, taste, and flavor of dried products.

According to Fellows (2000), Vacuum drying is performed in the absence of oxygen, so this method of drying protects sensitive components of foods from oxidation. As such, it is evident that the vacuum drying has an advantage over hot air drying. Furthermore, since some materials are sensitive to heat damage, vacuum drying is the better choice compared to hot air drying; this is because the vacuum can reduce the necessary drying temperature.

Mousa and Farid (2002) dried banana slices with MW under vacuum. They examined the thermal and drying efficiencies during the whole period of drying. Conclusion was that these two values are almost 100% at the beginning of process, but rapid drop can be observed as moisture content decreases. The effect of low pressure is particularly important at low moisture values.

Jaya and Das (2003) evaluated the effect of different drying conditions and modified mango pulp composition on drying time, color and effective moisture diffusivity. The variables tested were initial thickness of pulp (2–4 mm) and vacuum chamber plate temperature, i.e., drying temperature (65–75°C). Drying pressure was kept constant at 30–50 mmHg. The drying kinetics was adequately fitted by a model based on effective moisture diffusivity. Increase in pulp thickness and drying temperature led to increase in effective moisture diffusivity. Increased drying rates were associated with low product thickness and high temperatures. With regard to color, the reconstituted pulp powder was used as sample. The higher the product layer and the drying temperature, the higher the total color changes. In conclusion, it was recommended the use of a product layer lower than 2.6 mm and a drying temperature lower than 72.3°C for obtaining high quality dried mango pulp.

Falade *et al*., (2003) studied the osmotic pretreatment stage, and sensory attributes of osmotically dehydrated oven dried and osmotically dehydrated vacuum dried cashew apple products. Osmosed samples were subsequently dried in either an air oven (50°C) or a vacuum drier (50°C) both for 6 h. The water loss, solid gain and percentage weight reduction increased with increasing osmotic solution concentration and immersion time, but decreased with increasing slice thickness. Sample pre-osmosed in 60 °Brix and 68 °Brix solutions were significantly better than pre-osmosed in a 51 ^{0}Brix solution. A significant difference between the osmo-oven and osmo-vacuum dried cashew apples could not be ascertained.

Jena and Das (2007) explained the vacuum drying of coconut press cake, a by-product of the coconut processing industry. The main contribution of this study was the development of a new thin-layer drying model, which adequately fitted the changes in coconut press cake moisture content during vacuum drying. Experiments were carried out by using a 32 factorial design where sample thickness (2–4 mm) and drying temperature (65–75°C) were varied. Pressure was fixed at 62 ± 3 mmHg. Faster drying was associated with high temperature and low thickness.

Amellal and Benamara (2008) claimed the drying ability of date (Phoenix dactylifera L.) pulp cubes for three Algerian common varieties (Mech-Degla, Degla-Beida, and Frezza). Drying process was carried out under partial vacuum (200 mbar) at 60, 80, and 100°C. Compared to the Newton model, the Henderson and Pabis model better described drying kinetic of Mech-Degla and Frezza pulps at 60 and 80°C with a mean relative error not higher than 6.07%.

Thanit Swasdisevi *et al.,* (2007) studied that Combined Far-Infrared Radiation (FIR) and vacuum drying which has recently received more attention since the technique was proved effective in drying some types of fruits with the aim to produce fat-free fruit based snacks. However, most studies are of experimental nature. In this study a mathematical model, which allows prediction of the changes of moisture content and temperature of a model food material (banana) undergoing combined FIR and vacuum drying was developed. The predicted results were compared with the experimental results at the absolute pressures of the drying chamber of 5, 10, and 15 kPa and at the controlled banana center temperatures of banana of 50, 55 and 60°C. Based on the comparison between the predicted results and the experimental results, it was found that the developed model performed adequately in predicting the changes of the moisture content. The simulated temperature at the center of a banana slice was higher than the experimental temperature during the first 50 min of drying but agreed well with each other afterwards.

Lee and Kim (2009) reported that radish slices were dried as single layers with thickness of 4 and 6 mm in the ranges of 40–60°C of drying air temperature in a laboratory scale vacuum dryer. Moisture transfer from radish slices was described by applying the Fick's diffusion model, and the effective diffusivity changes between 6.92×10^{-9} and 14.59×10^{-9} m^2/s within the given temperature range. Effective diffusivity increased with increasing temperature. An Arrhenius relation with activation energy values of 16.49 and 20.26 kJ/mol for the thickness of 4 and 6 mm expressed the effect of temperature and sample thickness on the diffusivity.

Ashaf *et.al.,* (2012) explained on date paste behavior and characteristics of date paste at temperatures of 60, 70, and 80ºC as thin layer with sample thicknesses of 1, 1.5, and 2 cm in a laboratory scale vacuum chamber. Modeling of drying kinetics of date paste was investigated based on the specific temperatures and sample thicknesses. The experimental moisture loss data were fitted to eight thin layer drying models available in the literature. The modified Henderson-Pabis, Verma, and Jena-Das models showed better fitness to the experimental drying data compared to the other models. The effective moisture diffusivity ranged between 6.0854×10-8 and 4.868×10-7 m2 s-1. Effective diffusivity increased with the increase in temperature and sample thickness.

Sumic *et al*., (2013) studied on optimizing the vacuum-drying of frozen sour cherries in order to preserve health-beneficial phytochemicals, as well as textural characteristics. Investigated range of temperature was 46–74°C and, of pressure, 17–583 mbar, in a new design of vacuum-dryer equipment. The total solids, a_w value, total phenolics, vitamin C, antioxidant activity, anthocyanin content, total colour change and firmness were used as quality indicators of dried sour cherry. Within the experimental range of studied variables, the optimum conditions of 54.03°C and 148.16 mbar were established for vacuum drying of sour cherry. Separate validation experiments were conducted, under optimum conditions, to verify predictions and adequacy of the second-order polynomial models. Under these optimal conditions, the predicted amount of total phenolics was 744 mg CAE/100 dw, vitamin C 1.44 mg/100 g per dry weight (g dw), anthocyanin content 125 mg/100 g dw, IC_{50} 3.23 mg/ml, total solids 70.72%, a_w value 0.646, total colour change 52.61 and firmness 3395.4 g. The investigated parameters had a significant effect on the quality of the dried sour cherries.

Saberian *et al*., (2014) reported the vacuum drying of loquat fruit (*Eriobotrya japonica* Lindl.). More specifically, the influence of different drying temperatures on the drying time, drying rate and effective moisture diffusivity was evaluated and the drying was tentatively modeled by nine thin layer drying models. Vacuum drying was performed at 60, 70 and 80^0C and a vacuum of 52 cm Hg (absolute pressure of ~32 kPa). Results showed that the higher the temperature, the higher the drying rates and the shorter the drying time.

2.4 STORAGE STUDIES

2.4.1 Modified Atmosphere Packaging

Hotchkiss and Banco (1992) claimed that Modified atmosphere packaging (MAP) and controlled atmosphere (CA) storage are the two techniques to reduce the oxygen around the food and are largely used for the preservation of fresh produce. There have been great technological advances in this area of preservation, particularly as it refers to improving the quality and shelf-stability of highly perishable food products, such as produce. However, when using these technologies, careful attention must be paid to the effect on the survival and growth of pathogenic organisms. MAP may slow the rate of deterioration of the produce but could also provide sufficient time for human pathogens to grow, rendering the product unsafe while still edible.

O_2, CO_2 and N_2, are most often used gas mixtures in MAP/CA storage studies (Parry, 1993; Phillips, 1996). Other gases such as nitrous and nitric oxides, sulphur dioxide, ethylene, and chlorine as well as ozone have been suggested and investigated experimentally by Parry (1993) and Philips, (1996).

According to Yam and Lee (1995) the major goal of MAP is to reduce the growth rate of microorganisms, which cause the product to become organoleptically unacceptable. However, pathogens do not cause organoleptic changes in many cases. MAP can delay senescence in vegetables and therefore lessen susceptibility to pathogens.

2.4.2 Packaging Materials

Kader *et al.*, (1989) stated that the initial gas composition in packaging material must be determined for each fruit or vegetable product since too little oxygen or too much carbon dioxide results in irregular ripening, browning and other changes in organoleptic properties.

Mathlouthi and Leiris (1990) explained that most of the packs for MAP products are made from one or more of four polymers: polyvinylchloride (PVC), polyethylene terephthalate (PET), polyethylene (PE) and polypropylene (PP) depending on the features desired for the intended use. The choice of packaging material destined to protect the food product during the storage should not ignore the physical and chemical properties of the packaged food. Packaging of the food product is an operation, which aims the prevention of all kinds of degradation that render it unsuitable for consumption or of a lower sensorial value.

Jenkins and Harrington, (1991) claimed that, the packaged item respires, as it consumes O_2 and generates CO_2. Thus the O_2/CO_2 ratio continues to decrease until it reaches a level at which permeation of the two gases though the package, O_2 in and CO_2 out, balances the rate of generation and consumption of the two gases. In the ideal case, a film with adjustable O_2 and CO_2 permeation rates could be used to establish within the package any desired steady state O_2 /CO_2 ratio; this ideal ratio will be different for every produce item. To achieve something close to the desired O_2/CO_2 ratio range in the package, the film permeability characteristics should be such that its CO_2 permeability is three to five greater than its oxygen permeability. These requirements are best obtained by low density polyethylene (LDPE) and polyvinyl chloride (PVC), and for this reasons these films are the most widely used for wrapping produce

The particular importance for MAP is that polyethylene, particularly low density polyethylene, tends to have a high ratio of CO_2 to O_2 permeability (Kader *et al*., 1989). This is important in allowing O_2 concentration to decrease without an associated excessive buildup of CO_2 inside the package.

Gorris and Peppelenbos (1992) reported that MAP slow down the metabolic activity of a product and of the microorganisms present, both spoilage and pathogenic, limiting the O_2 supply and applying an elevated level of CO_2.

Robertson, (1993) studied that LDPE films are generally used for packaging of apple, carrots and tomatoes, which have low respiration rate but not suitable for fruits and vegetables which have high respiration rates. LDPE is the most widely used polyethylene (PE) version which has good tensile strength, burst strength, impact resistance and tear strength, retaining its strength down to 60°C. While it is an excellent barrier to water vapor, it is not a good barrier to gases. In addition, because of its very good heat sealing properties, it is widely used as the food contact and sealable layer in laminated packages.

Beaudry and Lakakul, (1995) concluded that as the temperature increases, the permeability of the packaging film to O_2 and CO_2 increases. They also reported that the permeability of O_2 and CO_2 though low-density polyethylene (LDPE) increases approximately 2.5 fold between 0 and 15°C. However, (Kader *et al*., 1989) reviewed that the permeability of some package films has been raised from two to five times with every 10°C increase in temperature.

Pereira and Rodrigues (2004) explained the quality of minimally processed guavas, osmotically dehydrated and packed under passive modified atmosphere, were evaluated during 24 days of storage at 5°C. Modified atmosphere packaging in polyethylene terephthalate (PET) containers had a strong influence on color preservation and weight loss of the guavas. Significant changes in the texture were found but the color of the fresh fruit remained unchanged. The combinations of storage temperature, modified atmosphere packaging, and the osmotic dehydration process maintained the quality of the guavas during 24 days of storage.

Isaak *et al*., (2004) studied the effect of modified atmosphere packaging on the shelf-life of plantains. A steady state of about 5.01% CO_2 and 4.2% O_2 in the modified atmosphere of low density polyethylene (LDPE) films between 20 and 24 days was established. MAP considerably delayed compositional changes in fruit color, fruit texture, pulp to peel ratio, total soluble solids (TSS) as compared to openly kept plantains during EC storage. Results indicate that the shelf-life of MAP plantains could be extended up to 35 days as compared to openly kept plantains for 16 days under EC storage.

2.5 QUALITY CHARACTERISTICS

According to Sokhansanj and Jayas (1995) drying at elevated temperatures affect the three quality degradations of the food products. These three qualities are in terms of chemical quality such as browning reaction, lipid oxidation, and color loss; physical quality such as rehydration, solubility, and texture; and nutritional quality such as vitamin loss, protein loss and microbial survival. In this study, however, only ascorbic acid degradation and color change of the product as affected by the drying processes are considered.

Quality is defined as the absence of defects or degree of excellence and it includes appearance, color, shape, injuries, flavor, taste, aroma, nutritional value and being safe for the consumer (Abbott, 1999).

2.5.1 Total soluble solids

The physiological maturity of the fruit at harvest is a major determinant of quality and TSS. Sugar import in vine-ripened fruit increases in the latter stages of ripening (Carrari *et al.,* 2006).

Haque (1993) found that the average total soluble solid of thee clones of jackfruit having very soft, intermediate and firm type of pericarp are of 17.66, 16 and 14.11 °Brix respectively.

Rosnah *et al*., (2009) reported that many researchers have identified indicators of fruit maturity based on measurement of size, weight or density, physical attributes; such as colour, firmness and moisture content; as well as other chemical attributes such as starch, sugar or acid contents or morphology evaluation.

Fernandez *et al.*, (2005) had conducted a study for determining TSS of apples using nondestructive sensors which retains the total soluble solids without any change in the sugar content of apples. The greater weight loss in strawberries compared to packaged fruit was associated with lower acidity, and lower soluble solids content. (Nunes *et al*., 1995).

2.5.2 Vitamin C

Ascorbic acid is the water-soluble vitamin and sensitive to heat (Erdman and Klein, 1982; Moser and Bendich, 1991). The degradation of ascorbic acid can cause the quality loss and color formation of product. The color formation can also occurred by other ways such as browning and pigment degradation. Both of ascorbic acid degradation and color formation are well appeared in the thermal processing. Therefore, ascorbic acid content and color are important factors for fruit and vegetable products and are subjected to appreciable change during the drying process.

Erdman and Klein (1982) also stated 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 is dependent 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 (Villota and Hawkes, 1992; Ottaway, 1993).

Hoque (1993) reported vitamin C content of 12 mg per 100 g in the unripe and 10 mg per 100 g in the ripe jackfruit bulb, respectively. He also reported the vitamin C content of the Ghila type of jackfruit pulp was found to contain 7.7 mg.

Prolonged storage of fruits results in losses in vitamin C and changes under cold conditions are less as compared to room temperature (Pal *et al*., 1995).

Lee and Kader (2000) studied that the loss of vitamin C after harvest can be reduced by storing fruits and vegetables in reduced O_2 and/or up to 10% CO_2 atmospheres; higher CO_2 levels can accelerate vitamin C loss. Vitamin C of produce is also subject to degradation during processing and cooking.

Piga *et al*., (2003) investigated the effect of refrigerated storage on polyphenols and ascorbic acid content and in manually peeled whole cactus pear fruits packaged with a low gas barrier film and had found out that ascorbic acid showed no significant variations during the processing.

Serpen *et al*., (2007) claimed that vitamin C is a water soluble vitamin that is widely considered as an appropriate marker for monitoring quality changes during processing, storage and at the end point of the frozen chain. This is a consequence of its concentration change due to irreversible oxidation mechanisms that are enhanced by temperature abuses.

L-Ascorbic acid (L-AA), or more commonly used Vitamin C, is a water soluble vitamin that is found in many fruits and vegetables. L-ascorbic acid and D-ascorbic acid acts in a chemical manner, similar to L-AA, but have no vitamin C activity, and no nutritional value (Damodaran, 2008)

2.5.3 Texture

Ramana and Taylor (1994) stated that texture is another important parameters connected to product quality, which is related to the structure of foods Textural characteristics also depend on chemical and biophysical characteristics of the products (Mohsenin, 1986; Bourne, 1992; Thiagu *et al.*, 1993).

Beveridge and Weintraub, 1995 reported that during blanching, as the water activity reduces the texture hardness of the fruit increases for apple slices.

Gorny *et al.*, (1998) reported that storing the products at low temperature will maintain the texture significantly.

According to Fellows (2000) pretreatment as peeling, cutting and blanching causes major changes to the product, and factors that influence the texture change could be gelatinization of starch, or crystallization of cellulose. This leads to internal stress to the cells, and the cell walls gets cracks, and get compressed. The surface of the dried product gets shriveled, and matt. When the products are rehydrated, the water absorption is slow, and the rehydrated material will not obtain the same firm and crisp texture as the fresh raw material. The degree of textural changes to the dried and the rehydrated material varies between different products, their DM and solutes present. Some get a tough and sticky consistency, and others get hard and crispy. The degree of drying also affects the textural appearance. High temperature and fast drying generally gives a greater change in texture compared to lower temperature and moderate drying time

Cano Chauca *et al.,* (2002) observed that quality parameters for colour and texture involved during the drying process of bananas. The effects of the drying temperature on dried banana were determined. Air temperature of 50°C, 60°C and 70°C were used with a drying air speed of 1.5 m/s. The colour was evaluated electronically using a colorimeter. The banana colour varied during the drying process. The colour of the dried product was most altered at 70°C where as 50°C and 60°C presented less colour alteration Texture was evaluated using texture analyzer and varied during the drying process.

Besides loss in firmness, fruits after harvesting undergo different chemical and biological phenomenon such as decay, deformation of original structure, weight and changes in firmness and reduction in overall appearance (Aquino and Palma, 2003).

Firmness is one of the components of texture which is a complex sensory attribute that also includes crispiness and juiciness (Konopacka and Plocharski, 2003) and is critical in determining the acceptability of horticultural commodities (Abbott and Harker, 2004).

2.5.4 Colour

Maillard reaction limits the shelf life of various dehydrated fruits, vegetables, citrus products, and juice during the storage studies (Handwerk and Coleman, 1988).

McEvily *et al.,* (1992) discussed browning of foods which results from both enzymatic and non-enzymatic oxidation of phenolic compounds as well as from Maillard reaction that occurs when mixtures of amino acids and reducing sugars are heated

Shewfelt, (1986) claimed the necessary constraints to retain light colour of products, enzymatic browning which is a problem in drying industry for a great number of commodities, for example, fruits like apples, bananas and grapes, vegetables like potatoes, mushooms and lettuce undergoes changes in colour attributes. These reactions usually impair the sensory properties of products due to associated changes in colour, flavor and texture, besides nutritional properties, which are undesirable (Martinez and Whitaker, 1995). Hence, the regulation of colour is important for improving quality of dried products.

According to McGuire (1992) the most common technique to assess the colour is by colorimeter. There are several colour scales in which the surface colour can be represented. The 3-dimensional scale *L**, *a* and *b** is used in Minolta chomameter. The *L** is lightness coefficient, ranging from 0 (black) to 100 (white) on a vertical axis. The *a** is purple-red (positive *a** value) and blue-green (negative *a** value) horizontal axis. Second horizontal axis is *b**, that represents yellow (positive *b** value) or blue (negative *b** value) colour.

Wakayama (1995) studied the effect of temperature on PPO activity in Japanese apple. It was found that for Fuji apple, the relative PPO activity decreased from 49% to 13% as the temperatures increased from 50 to 60°C and the enzyme was reduced to an undetectable level at temperature above 70°C.

The color of the dried products often comes out matt and pale compared to the fresh material, due to the dry surface reflects the light in another way. In vegetables, a carotenoid and chlorophyll pigment goes though chemical changes caused by heat and oxidation. Residual polyphenoloxidase enzymes could lead to browning during storage. Blanching the products before drying could prevent this (Fellows 2000).

Giese (2000) reported that colour of foods is an important quality attribute in marketing. Though it does not reflect nutrition or flavor, it is important as it relates to consumer preference based on appearance.

Krokida and Maroulis (2000) investigated the drying process of banana using five methods (conventional, vacuum, microwave, osmotic and freeze drying) and various drying conditions extensively. By changing drying methods, they found the lighteness parameter (L*) decreased significantly during air, vacuum, osmotic and microwave drying, while increased slightly in freeze drying; the redness (a*) value increased significantly during air drying, followed by microwave and vacuum drying, then freeze drying, while keeping constant for osmotic drying; the yellowness parameter (b*) showed a similar behavior to redness parameter (a*). When changing the conditions of conventional and vacuum drying, L* is not affected by temperature and air relative humidity while a* increases as drying temperature increases and relative humidity decreases, b* increases as drying temperature decreases and relative humidity increase. Usually, the increase of *Chroma* parameters (a* and b*) means the samples experienced an extensive browning. Freeze drying removes water by sublimation of ice and prevent enzymatic browning reaction, resulting in relative stability of colour parameter (L*, a*, b*). Hence, a conclusion that freeze drying yields the best colour preservative method but conventional drying is the worst can be drawn.

According to Maskan (2001) and Maskan *et al.*, (2002) the color measurement is normally done in an indirect way to estimate the color changes of foods since it is simpler and faster than the chemical analysis.

Hunter *Lab* system is one type of measuring color systems. It has proven valuable in describing visual color deterioration and providing useful information for quality control in various fruits and vegetables during drying such as tomato (Zanoni *et al.*, 1999), kiwifriut (Maskan, 2001), banana and guava (Chua *et al.*, 2002) and mango pulp (Jaya and Das, 2003). The color parameters are expressed as *L* (whiteness or brightness/darkness), *a* (redness/greenness) and *b* (yellowness/blueness).

Beaudry *et al.,(*2003) used the colour scale to evaluate the colour of microwave/hot air, conventional hot air, freeze and vacuum dried cranberries, and concluded that there is no significant difference among different drying treatments, in spite of expected darker colour of berries subdued to higher temperatures.

Venkatachalapathy (1998) used the similar technique, but with one new value ratio of *a** and *b**, where higher *a*/b** ratio indicates a darker product. He determined a significant difference between freeze dried and MW/hot air dried strawberries, where microwave-hot air dried had lower *a*/b** ratio.

Yongasawatdigul and Gunasekaran (1996) compared MW/vacuum dried cranberries with those conventionally dried in the same system as described above (Z*, *a*, b*, h*°, C*, *ΔE),* and concluded that MW/vacuum dried cranberries resulted in a better quality product than hot-air drying method. Also, the redness *(a*)* decreased with storage time.

L* is the degree of lightness of the colour. This refers to the relation between reflected and absorbed light. L* values equals to zero for black and 100 for white, a* (red-green) is the degree of redness (0 to 60) or greenness (0 to 60) and b* (yellow-blue) is the degree of yellowness (0 to 60) or blueness (0 to 60) (Perez and Gonzalez 2003).

Ali *et al.,* (2011) performed a study on colour changes occur in kiwifruit during dry process in order to determine the magnitudes of the parameters for a corresponding colour change model. The drying experiments were carried out at air temperatures of 40, 50, 60, 70 and 80°C, at air velocity of 1.0 m/s and kiwifruit slice thickness of 4 mm. The colour parameters for the colour change of the materials were quantified by the Hunter *L* (whiteness/darkness), *a* (redness/greenness) and *b* (yellowness/blueness) system. These values were also used for calculation of the total colour change (Δ*E*), *chroma*, hue angle and browning index. The values of *L* and *b* decreased, while values of *a* and total colour change (Δ*E*) increased during hot air drying. The mathematical modeling study of colour change kinetic showed that changes in *L*, *b* values, *Chroma* and browning index fitted well to the first-order kinetic model while *ΔE, a* value and hue angle followed the zero order kinetic.

2.5.5 Moisture content

Food Composition Table for Use in East Asia (FAO, 1972) reported the moisture content of tender jackfruit as 84 per cent and that of ripe jackfruit as 77% by Purseglove (1968) and Bhatia *et al.,* (1955).

Hossain and Hoque (1979) studied different chemical composition in jackfruit bulb, they stated that the average moisture and dry matter content of jackfruit pulps were 76.37 and 23.63 percentage.

Sokhansanj and Jayas (1995) stated that the moisture content of high moisture food is reduced to 20-25% by a conventional method, such as hot air drying and then vacuum is applied to bring the moisture down to 1-3%.

Unde *et al.*, (2001) conducted an experiment in drying of banana slice. The drying was carried out in tray drier at 60°C for 5 hour. Moisture content of the banana slices during the drying period decreased exponentially. The quality of dehydrated banana slices treated with 0.25% KMS + 0.05% CaCl, 0.25% KMS + 1% CaCl and 60 °Brix sugar syrup + 0.05% CaCl was found to be very good. Whereas products from all other treatments were graded as good.

Masomeh *et al.*, (2014) claimed that the optimum conditions for minimum moisture content and maximum rehydration ratio include: Temperature 56°C, vacuum pressure of 10 kPa and the drying time of 250 minutes, was the effective way to obtained moisture content of 23% and of rehydration ratio was 1.45%.

2.6.6 Rehydration ratio

According to Salunkhe *et al*., (1991) the first aim of drying is removing of water because dried food has numerous advantages. But, before consumption of this food, it has to be rehydrated by adding of water. Factors that affect rehydration are time, temperature, air displacement, pH and ionic strength. Rehydration rates can be hosted by ultrasonic treatment of the rehydrated product placed in water.

Krokida and Maroulis, (2000) stated that the rehydration characteristics of the dried product are influenced by processing conditions, sample constitution, preparation of the sample prior to rehydration and extent of the structural and chemical changes induced by drying.

Potter and Hotchkiss, (1995) claimed that drying processes changes the product composition in lesser extent which are suppose to offer better rehydration ratio of finished product. An example of these processes is freeze drying, which offers the smallest changes in structure and therefore the best rehydration capacity. This phenomenon can be explained by physical shinkage and changes in physicochemical composition during drying at colloidal level.

Fellows (2000) concluded that when rehydrating a dried product, it will never regain the same condition as before drying. The drying process causes changes in the permeability of the cell walls, loss of osmotic pressure and solute migration. Crystallization of polysaccharides and coagulation of proteins also contribute to irreversible changes of the plant tissue. The less elastic cell walls and the reduced water holding capacity of protein and starch, all decrease the rehydration ratio (RR) of the products. If the drying process is optimal, the negative factors regarding rehydration of the cells will be less than with a poor drying technique

Velic *et al*., (2004) investigated airflow velocity influence on the kinetics of convection drying of apples, heat transfer and average effective diffusion coefficients. Drying was conducted in a convection tray drier at drying temperature of 60°C using rectangle-shaped (20x20x5mm) apple samples. Rehydration ratio was used as a parameter for the dried sample quality. Kinetic equations were estimated by using an exponential mathematical model. The result of calculations corresponded well with experimental data. Two well-defined falling rate periods and a very short constant rate period at lower air velocities was observed. With an increase of airflow velocity an increase of heat transfer coefficient and effective diffusion coefficient was found. During rehydration, about 72% of water removed by the drying process was returned.

Giri and Prasad (2007) studied the quality characteristics on microwave dried button mushooms dehydration. The microwave showed better rehydration capacity than other method and is due to the internal structure remains same during process and also stated that microwave vacuum dried products tented to have a porous and non shrunken structure with excellent rehydration capacity.

2.7 MICROBIAL ANALYSIS

Frazier and Westhoff (1978) studied that no microorganisms like yeast, mold and bacteria will grow in the food products of moisture content less than 15% (w.b).

The effect of MAP on yeasts is negligible, however, molds are aerobic microorganisms and therefore CO_2 can cause growth inhibition at concentrations as low as 10%), although the effect is not fungicidal. CO_2 levels > 10% or O_2 levels < 1% are needed to suppress fungal growth, (Molin, 2000).

Adams and Moss (2000) studied that the temperature in the driers may kill some of the bacteria, but many will survive, and could even get more heat resistant during the process. During night time, the air also gets more humid, and the products will absorb some of the moisture from the surroundings

Adams and Moss (2000) also stated that microorganisms can grow over a wide range of temperature. Some psychophillic strains can grow at temperatures down to – 5 $^{\circ}$C, and in the other end of the scale we find thermopile organisms that grow at 90 $^{\circ}$C. Many microorganisms will survive at temperatures both higher and lower than those mentioned, and can start grow again when temperature is back at the bacteria's optimum. Bacteria strains as certain *Bacillus* and *Clostridium* species can produce spores that are extremely resistant to external influence as freezing, heat, drying and chemicals. Under the right conditions the spores can germinate, and the bacteria will start to grow again.

Molds and yeasts are often present in dried fruits and vegetables. (Hell *et al.,* 2009)

According to Robertson (2006), the causes of spoilage in foods due to microorganisms can be divided into two factors, being intrinsic and extrinsic. The intrinsic factors are pH, a_w, and nutrient content, while storage temperature, relative humidity of the environment, and the concentration of gases in the environment are the extrinsic factors. Therefore, an understanding of these causes of the deterioration, and the appropriate storage conditions for food products is necessary.

2.8 SENSORY ANALYSIS

The physical changes in dried food products are frequently caused by storage in inappropriate conditions. As a result, the shelf life of the products may be significantly reduced. For example, when dehydrated foods are stored at high humidity, the process of moisture uptake will take place. As a result, the products become soggy, leading to degraded quality and shortened shelf life (Singh, 2000)

Beaudry *et al*., (2003) used numerical sensory evaluation scale of 1-7, from "like extremely" to "dislike extremely", respectively.

Venkatachalapathy (1998) worked with a panel of ten or more untrained judges for his sensory analysis of dried strawberries and blueberries, whereas used visual quality assessment scale ranging from 9 to 1, representing range of excellent quality to extremely poor, respectively.

Tulasidas *et al*., (1995) used scoring panel of 10 judges to determine the quality attributes of MW/convective dried grapes, and the ratings assigned were given to a scale of 0 to 5 points, where 0 is the highest quality and 5 points the poorest. Sensory appearance is of high importance, because it is the first characteristic observed by consumer. Appearance quality includes visual sensations that can be perceived by senses. These include (but are not limited to) size dimensions, shape, color, uniformity and intensity, stiffness under fingers, smell (odour), taste (sweetness, sourness) and others. Since this is purely subjective factor, it is not consistent though out different experiments.

The degradation of sensory quality and nutritional quality can be caused by chemical reactions. The main two causes of chemical changes during storage are the interaction between the internal food components and the external environmental factors. Environmental factors such as light, oxygen, temperature and Aw affect the rate of lipid oxidation in foods during storage. The deterioration rate will accelerate in foods containing high unsaturated fatty acids when keep at inappropriate conditions, such as an exposure to oxygen or high temperature. Additionally, chemical reactions are related to enzymatic action, lipid oxidation and non-enzymatic browning; these reactions are responsible for undesirable changes in colour, flavors and nutritive values (Singh, 2000; Robertson, 2006).

Texture is a way that food feels to the tongue when eaten. From a physicochemical point of view, Jongen (2000) defines the texture in terms of cell wall composition and structure. Texture and consistency are evident chemo-structural features of fruits and vegetables, and are the attributes of a primary importance. Textural characteristics can be measured by any standard procedure.

According to Bruckner and Auerswald (2000), texture together with appearance and colour is one of the most important and assessed properties.

Texture - Sensory panel evaluation is used to determine the crispness of foods and still is the primary method used in the food industry. How sensory evaluation relates to instrumental evaluation has been extensively studied (Carolyn, 2009).

Flavor is a combination of taste and odor (Potter and Hotchkiss, 1995). Taste is the perception of specific compounds on the tongue. Basic taste includes salty, sweet, bitter, and sour, which associate to different chemical compounds. Umami and astringency also have been suggested as tastes by some researchers (Chisten and Smith, 2000). Odor, which is perceived in the olfactory center in the nose by chemical stimuli, is even more complex than taste. Under normal conditions, we only detect volatile chemicals that can reach the olfactory epithelium (Dodd, 1992).

Human sensory evaluation of flavor still is used as the gold standard in the food industry. However, combining sensory measurements with instrumental evaluation may provide a more complete picture of products (Carolyn, 2009). Analytical chemistry techniques are employed to determine the chemical components of products that contribute to taste and odor. High-pressure liquid chomatography (HPLC) is used to separate non-volatile compound such as sugars or organic acids and Gas chomatography (GC) is used to analyze volatile compounds such as aroma (Marsili, 2007). Electronic noses and tongues are widely applied for instrumental sensory evaluation.

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

This chapter deals with the preparation of raw materials and the experimental procedures adopted in preserving the jackfruit. It also describes the instrumentation and methodology used for quality analysis of vacuum dried jackfruit *viz.*, colour, vitamin C, TSS, texture, pH, and moisture content are also discussed in detail. All the experiments were triplicate and the mean values were taken for the statistical analysis.

3.1 COLLECTION AND PREPARATION OF JACKFRUIT SAMPLES

Ripen jackfruit (*Artocarpus heterophyllus* L.), which belongs to the 'Varikka' variety were procured from the K.C.A.E.T Instructional Farm, Tavanur (2014 and 2015) and Regional Agricultural Research Station, Ambalavayal, Wayanad district. The collected jackfruits were washed in tap water and cut into pieces and the bulbs were separated from the rind of the jackfruit using a stainless steel knife. The bulbs were further separated from the seeds and kept in stainless steel plates for further analysis.

3.2 STANDARDIZATION OF PRETREATMENTS

Pre treatments such as steam blanching and steam blanching along with citric acid in two concentrations were given to reduce the enzymatic browning and to enhance the drying operations.

3.2.1 Pre-treatment with steam blanching

Steam blanching is 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 is reduced compared to water blanching (John *et al.*, 2004). Hence steam blanching was selected as a pretreatment prior to vacuum drying.

A batch type steam blancher (600×500 mm) consist of a blanching chamber, pressure releasing valve, inlet and outlet valve and pressure gauge was used for the study. A series of perforated stainless steel trays in which the materials were kept for blanching were placed parallel inside the blanching chamber.

Plate 3.1 – Steam blancher

Steam from a boiler was directly injected to the trays from bottom side of the chamber. The temperature inside the chamber was maintained as 100°C by adjusting the steam flow rate which is controlled by inlet valves. The quantity used for the study in each trial was 450 g. The blanching trials were carried for 20, 25, and 30 s durations.

3.2.2 Combination of steam blanching and citric acid treatments

Blanching along with citric acid was done to reduce the drying time (Doymaz, 2010). The concentration of citric acid was fixed as 0.3% and 0.5% with a dipping time of 5 minutes.

The treatments for this study were as follows:

B1: Control (un-blanched sample)

B2: steam blanching for 20 s

B3: steam blanching for 25 s

B4: steam blanching for 30 s

B5: steam blanching + 0.3% citric acid for 20 s

B6: steam blanching + 0.3% citric acid for 25 s

B7: steam blanching + 0.3% citric acid for 30 s

B8: steam blanching + 0.5% citric acid for 20 s

B9: steam blanching + 0.5% citric acid for 25 s

B10: steam blanching + 0.5% citric acid for 30 s

The pre-treatment was standardized based on hydrogen peroxide test, catalase test, colour and texture in terms of firmness and toughness. After the blanching process, the samples were cooled immediately in order to avoid overheating.

3.2.3 Standardization of blanching process by peroxidase and catalase tests.

3.2.3.1 Peroxidase Test

The ripened and deseeded jackfruit bulbs were crushed in a porcelain bowl immediately after blanching. Ten to twenty grams of crushed sample was taken in a test tube and 20 ml distilled water was added. Guaiacol (1%) and hydrogen peroxide (0.3%) solutions were added to the sample. Guaiacol solution (1 ml) and hydrogen peroxide solution (1.6 ml) were poured into the test tube and the contents were thoroughly mixed. A rapid and intensive brown-reddish coloration in tissue within 5 min indicated a high peroxidase activity. The gradual appearance of a weak pink color indicated an incomplete peroxidase inactivation or low peroxidase activity. If there was no color development after 5 min, the reaction was negative and the enzymes were considered inactivated.

3.2.3.2 Catalase Test

Jackfruit bulbs (approximately 2 g) were crushed immediately after blanching and mixed with 20 ml distilled water in a test tube. After 15 min, 0.5 ml of 1% hydrogen peroxide solution was added. A strong gas (oxygen) generation or bubble formation was observed within 2 to 3 minutes which indicates the presence of catalase, and no release of gas or no bubble formation showed the complete inactivation of catalase.

3.2.4 Colour

The Hunter's lab colorimeter (Make: Colour Flex EZ) was used to determine the colour of fresh and dried jackfruit bulbs as shown in Plate 3.2. The principle of working is by focusing the light and measuring energy reflected from the sample across the entire visible spectrum. The colorimeter has filters which rely on "standard observer curves" that measures the amount of red, yellow, green and blue colors. The colour of the jackfruit bulbs was measured under a colorimeter 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 *L* is the lightness, ranging from 0 (black) to 100 (white), *a* represents the greenness and redness (+100 for red and -80 for green) while *b* shows yellowness and blueness (+70 for yellow and -80 for blue). In addition, *Chroma*(C) and the total color change (*ΔE*) were calculated from the value of *L, a* and *b* using Equation 3.1 and 3.2. *Chroma* indicates color saturation of the samples which varies from dull (low value) to vivid color (high value). The total color change (*ΔE*) is the parameter considered for the overall color change evaluation between dried samples and the fresh jackfruit samples. Fresh jackfruit samples (*L, a, b*) were used as the reference and a low *ΔE* value corresponds to a low color change from the reference grape samples.

$$Chroma,\ C = \sqrt{a^2 + b^2} \qquad 3.1$$

$$\Delta E = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2} \qquad 3.2$$

Where, *L, a, b* – colour coefficient for raw samples

L_0, a_0, b_0 – change in colour coefficient for raw and dried samples.

The colour of jackfruit samples 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.

Plate 3.2 - Hunter Lab Colorimeter

3.2.5 Textural characteristics

The texture properties of fresh and dried jackfruit bulbs were carried by using microprocessor regulated Texture Analyzer (Make: Stable Micro Systems, UK; Plate 3.3). Texture analyzer measures the force, distance and time. The fresh jackfruit bulbs were compressed using a cylindrical probe under a measure of force 2.5 kg in compression mode with a test speed of 5 mm/seconds and the dried jackfruit bulbs were compressed using a cylindrical probe under a measure of force 2.5 kg in compression mode with a test speed of 2 mm/seconds. The jackfruit samples were placed on the flat surface in the instrument and the double compression was subjected by a cylindrical probe of 5 mm diameter. The force deformation curve describes the texture properties like firmness and toughness of the sample.

Plate 3.3 - Texture Analyzer

3.3 STUDIES ON VACUUM DRYING

The vacuum dryer (Make: Milk Tech Engineers, Model-GMP and size (600×600 mm) consists of three parts namely hot water generator, condensation unit and control unit. Also consists of thee pumps namely hot water pump, vacuum pump and cold water pump.

Water was filled in the SS tank which feeds to water pump and hot water condenser. Then the drying time was set in min on digital process timer (0 – 999 minutes) and also the hot water generator was set from 30 - 80°C. After that the hot water pump, cold water pump and heater were switched on. The vacuum gauge showed 680 mm Hg vacuum after setting all these parameters. Once the drying was complete the vacuum pressure is released and then the product was taken out for the further analysis. The weight of the sample was taken at an interval of 1 h and the drying process continues until the desired moisture content of the sample is obtained.

Plate 3.4 – Vacuum dryer

3.3.1 Standardization of vacuum drying of ripened deseeded jackfruit bulb

The optimized blanched samples were placed in thin layer form in the trays of vacuum dryer for the drying process. The drying studies were conducted at vacuum chamber temperatures of 25, 30, 35, 40 and 45ºC which were adjusted with a thermostat at a constant vacuum pressure of 680 mm Hg. The weight of the sample was taken at an interval of 1 h and the drying process continues until the moisture content of sample becomes constant.

The dryer treatments were as follows:

D1: Drying at temperature 25ºC

D2: Drying at temperature 30°C

D3: Drying at temperature 35°C

D4: Drying at temperature 40ºC

D5: Drying at temperature 45°C

Standardization of drying temperature was based on moisture content, TSS, pH vitamin C, rehydration ratio, colour, texture and sensory attributes.

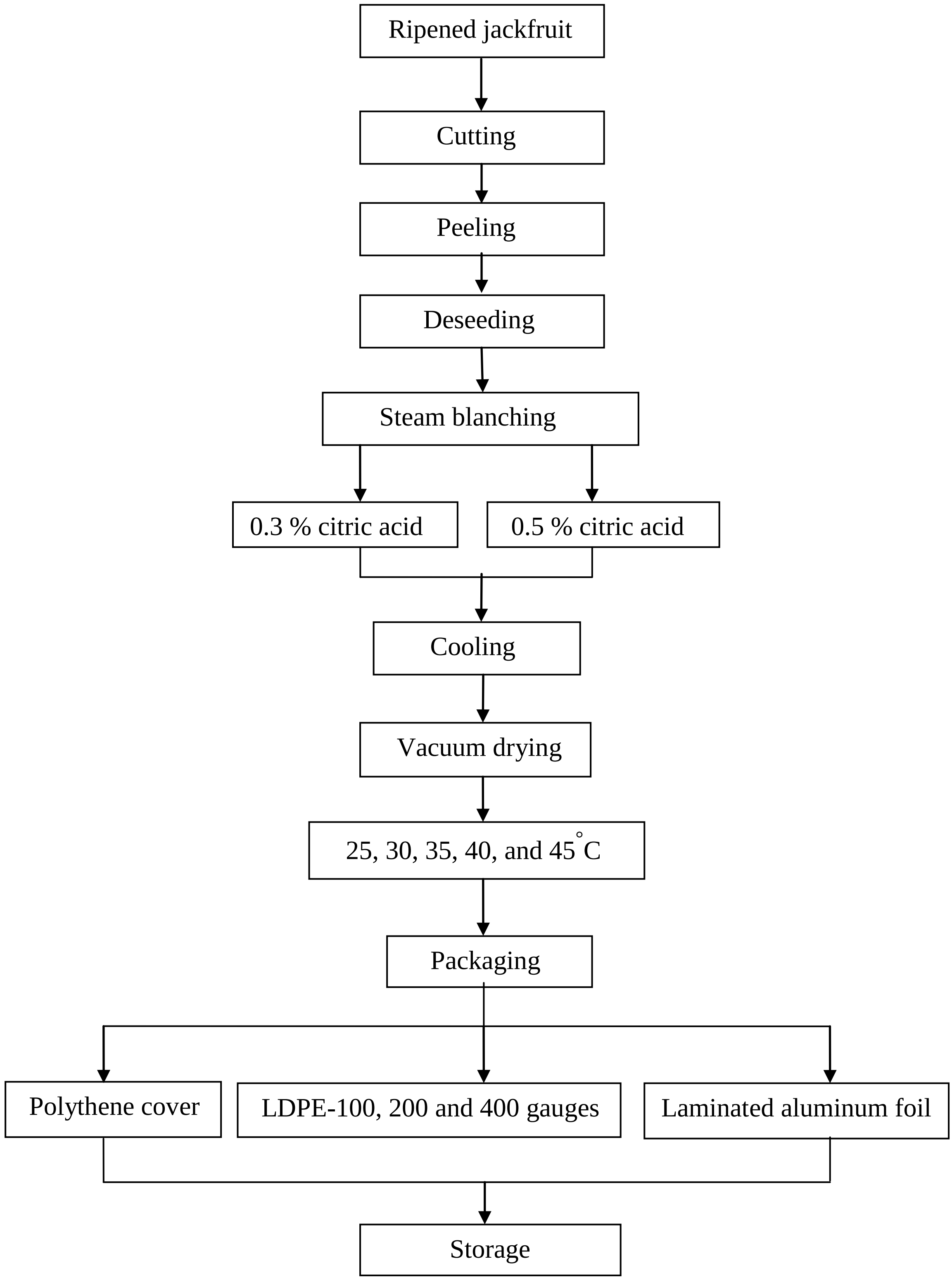

Figure 3.1 – Flow chart for vacuum drying of ripened deseeded jackfruit bulbs

3.4 QUALITY ANALYSIS OF VACUUM DRIED JACKFRUIT BULBS

3.4.1 Moisture content (%)

The moisture content of the fresh and dried samples were determined by the oven drying method by (Ranganna, 1986). Twenty gram of jackfruit sample was kept in the hot air oven maintained at 110°C for 1 hour. The mass of the sample was recorded as W_1. After drying, the sample were kept in desiccators and then weighed. The mass of the dried sample was recorded as W_2. The samples taken were replicated thrice and the average moisture content was recorded. The moisture content of the sample was calculated by using the following equation;

$$\text{Moisture content (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \qquad 3.3$$

Where,

W_1 = Initial weight of the sample, g

W_2 = Final weight of the sample, g

3.4.2 Total soluble solids

Two gram of the fresh and dried jackfruit bulb sample was taken and made into pulp using the processer. Two drops of jackfruit pulp was placed on (Make: ERMA) hand refractometer prism for finding the total soluble solids (Plate 3.6).

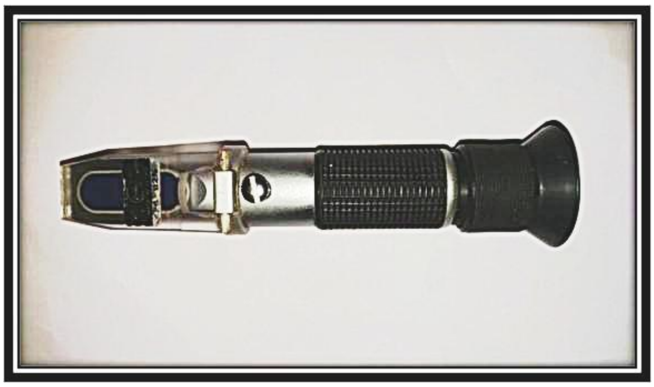

Plate 3.5 - Hand Refractometer

3.4.3 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) (Plate 3.5).

The pH meter was calibrated by the different buffer solutions of pH (4.0, 7.0 and 9.2). The sample was made into pulp by using processer 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.

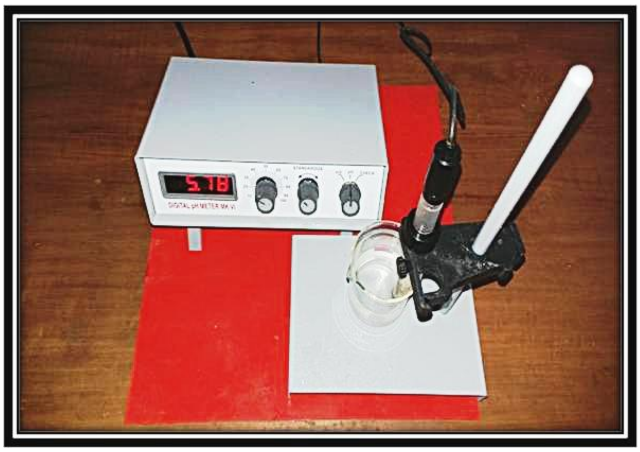

Plate 3.6 - pH meter

3.4.4 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. Then 5 ml each of working standard solution and 4% oxalic acid was pipette into a conical flask and titrated against the dye solution. The result point was the appearance of pale pink colour which is 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 is titrated against the dye (V_2).

The quantity of ascorbic acid (mg) present in 100 gm of sample was calculated as follows.

$$\text{Ascorbic acid (mg/100g)} = \frac{0.5}{V_1} \times \frac{V_2}{5} \times \frac{100}{V_S} \times 100 \qquad 3.4$$

3.4.5 Rehydration ratio

Rehydration is the process of refreshing the dehydrated or dried product by soaking in the distilled water. About 5 gm 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. The sample weight was recorded and the rehydration ratio was calculated according to the Equation:

$$\text{Rehydration ratio} = \frac{\text{Weight of rehydrated sample(g)}}{\text{Weight of dried sample(g)}} \qquad 3.5$$

3.5 STANDARDIZATION OF PACKAGING MATERIALS TO ENHANCE THE SHELF LIFE OF VACUUM DRIED JACKFRUIT BULB

Modified atmospheric packaging is done to extend the shelf life of dried product and to prevent the undesirable changes in the processed product, sensory characteristics, and nutritive value of foods. The three main gases used in MAP are nitrogen, oxygen, and carbon dioxide. Gas mixture was flushed to the packaging materials (Saxena *et al*., 2008).

This was conducted in a vacuum packaging machine with the provision of MAP (SEVANNA, India).

The different packaging materials with MAP were used to increase the shelf life of vacuum dried jackfruit bulbs.

The packaging materials used for the study are as follows.

P1: Packing in Polythene cover

P2: Packing in LDPE – 100 gauge

P3: Packing in LDPE – 200 gauge

P4: Packing in LDPE – 400 gauge

P5: Packing in laminated aluminum coil

Plate 3.7 – MAP Packaging machine

3.6 MICROBIAL ANALYSIS

Microbial analysis of the study involves the detection of bacteria, yeast and fungi which spoil the dried jackfruit bulbs during storage studies. The procedures adopted for microbial analysis is given below.

3.6.1 Enumeration of micro-organisms

Yeasts and mold counts was determined using Acidified Potato Dextrose Agar Oxoid (to pH 3.5 with 10% tartaric acid). A crushed sample of 1g was added to 90 ml of sterile water mixed with molten tempered Potato Dectrose Agar. The plates were incubated at room temperature for 5 days, and then the number of colonies found in the plates was recorded.

3.6.2 Standard plate count method

The dried jackfruit sample was crushed using mortar and 1 g of the crushed sample was added to 90 ml of sterile water (10^{-5} dilution) and shaken well for 10 to 15 minutes for uniform distribution of micro-organisms. For sterilized samples, the diluted sample was kept in a water bath at 80°C for 15 minutes before transferring to Petri dish for spore count determination. About 1 ml of diluted sample was transferred to a sterile Petri dish with a sterile pipette. Then the plates were rotated clockwise and anticlockwise direction for thorough mixing of the diluents and the medium. The plates are kept for 5 – 10 minutes for setting the medium. Then the plates were kept at room temperature for 1 to 2 days for bacterial growth and 3 – 4 days for spore formation (yeast and fungi). After the incubation period, the number of colonies (*cfu/g*) present was recorded.

3.7 SHELF LIFE STUDIES

The vacuum dried jackfruit bulbs were stored at ambient conditions (20 to 32°C and 66 to 93% relative humidity). The quality attributes like moisture content, TSS, vitamin C, pH, texture, colour and microbial analyses were performed for vacuum dried jackfruit bulbs in an interval of 15 days. Microbial analyses were performed for 10^{-5} dilution. The statistical analysis using completely randomized design (CRD) by Two Factor Completely Randomized Design was adapted for the study.

3.8 SENSORY ANALYSIS

The sensory evaluation of fresh and vacuum dried jackfruit with respect to colour, taste, texture and overall acceptability was judged on a 5 point hedonic scale (Ranganna, 1986) by a panel of 12 judges. The 5 point hedonic scale used for the sensory evaluation is shown below.

5 – Like very much; 4 – Like; 3 – Neither like nor dislike; 2 – Dislike; 1 – Dislike very much.

The sensory evaluation was carried out after the drying process for the optimized. The mean values of the scores were taken for the statistical analysis using Kendall's coefficient of concordance. The sensory evaluation card is shown in Appendix VIII.

3.9 COST ANALYSIS

The cost of vacuum dried jackfruit bulbs were determined with suitable assumptions using standard procedure which is given in Appendix IX.

3.10 STATISTICAL ANALYSIS

A statistical analysis was carried out to study the effect of all quality parameters on all the dependent variables. Analysis of variance (ANOVA) was conducted with Completely Randomized Design (CRD) for the optimization of quality parameters as discussed in this study and Kendall's coefficient of concordance test was assessed for sensory evaluation using SPSS software. The quality of dried samples during storage was analyzed by Two Factor Completely Randomized Design software.

RESULTS AND DISCUSSION

CHAPTER 4

RESULTS AND DISCUSSION

The outcome of the various experiments conducted to optimize the process parameter for vacuum drying of ripened deseeded jackfruit bulbs is narrated and discussed in this chapter. The chapter also discusses in detail the storage of the dried ripened deseeded jackfruit bulbs along with the quality aspects of the stored jackfruit bulbs.

4.1 PHYSICO – CHEMICAL CHARACTERISTICS OF FRESH RIPENED DESEEDED JACKFRUIT BULBS

The major physical and chemical characteristics of fresh ripened deseeded jackfruit bulbs (Varikka variety) were studied as per the procedure and the estimated values are presented in Table 4.1.

Table 4.1 – Physico – Chemical characteristics of fresh ripened deseeded jackfruit bulbs

Physico - Chemical characteristics		**Mean ± SD**
Moisture content (%)		82.68 ± 2.68
TSS (°Brix)		22.26 ± 2.31
pH		05.66 ± 0.29
Vitamin C (mg/100g)		07.76 ± 0.72
Texture	Firmness (N)	04.88 ± 4.60
	Toughness (Ns)	01.58 ± 0.73
Colour	*L*	61.03 ± 1.18
	a	08.89 ± 0.80
	b	52.15 ± 0.91

SD – Standard Deviation

A similar result was reported by Goswami *et al*., (2011) with moisture content of 80.04 - 84.44%, TSS of 19.3 – 27.00 °Brix, pH of 5.61 – 6.45 and vitamin C of 4.57 – 8.18 mg/100 g for different verities of jackfruit.

4.2 STANDARDIZATION OF PRE – TREATMENTS

Prior to vacuum drying the fresh jackfruit bulbs were subjected to different pre-treatments such as steam blanching and steam blanching along with citric acid at a concentration of 0.3% and 0.5% for 5 minutes. The influence of these treatments were assessed in terms of enzyme inactivation, colour (*L, a* and *b*) and texture attributes like firmness and toughness.

4.2.1 Effect of pretreatments on enzymatic inactivation

The ripened deseeded jackfruit bulbs were steam blanched as such and along with citric acid for different concentrations of 0.3% and 0.5% for a blanching time of 20, 25 and 30 s. The treatments are as follows B1 (control), B2, B3, B4, B5, B6, B7, B8, B9 and B10.

The blanching pretreatments were standardised based on the results obtained from hydrogen peroxide test and catalase test. The ripened deseeded jackfruit bulbs were subjected to steam blanching for different duration of time (20, 25 and 30 s), which observed negative results for both hydrogen peroxide and catalase test. The hydrogen peroxide test is done to detect the presence of peroxide enzyme which is indicated by pink colour on the addition of a drop of H_2O_2 and ethyl alcohol to the blanched samples. The time duration required to inactivate the enzyme could be considered as the optimum time for steam blanching of ripened deseeded jackfruit bulbs. In the present study, blanching time was standardized as 30 s which resulted in complete inactivation of the enzymes. Bai *et al.,* (2013) reported that steam blanching for 90 s was found to be the best for seedless grapes to inactivate the enzymes.

4.2.2 Effect of pre - treatments on colour attributes

The colour values in all the treatments showed significant ($p<0.05$) differences compared with the initial values. As the blanching time increases from 20 to 30 s there is a decrease in a and b value where as an increase in *L* value The effect of pretreatments on colour attributes is shown in the Table 4.2. It can be seen that the L value increases with increase in blanching time for all the treatments. These values show no significant difference with the time and this is mainly because of disintegration of chlorophyll pigment occurred during blanching. A similar change in color values was observed by Llano *et al.*, (2003) for kiwi fruit during steam blanching.

The effect of various citric acid concentrations used in blanching samples showed a gradual decrease in colour attributes in terms of a, b and increase in L value. Martinez *et al.*, (2013) reported that addition of citric acid or ascorbic acid during blanching increases the heat sensitivity of chlorophyll degrading enzymes, but reduction in pH contribute to degradation of chlorophyll. So citric acid pretreatments were not considered for further studies hence the sample having higher value of L, B4 was selected.

Table 4.2 – Effect of pre – treatments on colour attributes

Treatments	Colour attributes ± SD				
	L	A	b	ΔE ± SD	*Chroma*
B1	61.03±4.60[a]	8.89±0.73[a]	52.15±1.18[b]	-	52.90±0.02[f]
B2	63.09±0.55[a]	5.50±0.38[b]	51.43±2.00[a]	4.02 ±0.04[c]	51.72±0.02[c]
B3	63.18±0.55[a]	5.41±0.42[b]	51.35±1.98[a]	4.16±0.20[bc]	51.63±0.02[b]
B4	63.24±0.60[a]	5.38±0.42[b]	51.30±1.99[a]	4.23 ±0.04[c]	51.58±0.02[a]
B5	64.06±0.83[a]	4.20±0.30[c]	51.25±1.37[a]	5.65 ±0.04[c]	51.42±0.06[e]
B6	64.18±0.72[a]	4.19±0.30[c]	51.20±1.26[a]	5.73±0.20[ab]	51.37±0.02[e]
B7	64.30±0.79[a]	4.10±0.30[c]	50.10±1.31[a]	6.15 ±0.04[a]	50.26±0.02[d]
B8	64.57±1.28[a]	2.19±0.55[d]	50.07±0.91[b]	7.85 ±0.03[d]	50.11±0.03[i]
B9	64.67±1.28[a]	2.15±0.57[d]	50.05±0.92[b]	7.89 ±0.02[d]	50.09±0.03[h]
B10	64.73±0.33[a]	2.05±0.57[d]	50.02±0.93[b]	7.96 ±0.04[e]	50.04±0.03[g]

(B2 – Steam blanch for 20 s, B3 – Steam blanch for 25 s, B4 – Steam blanch for 30 s, B5 – Steam blanch + 0.3% citric acid for 20 s, B6 – Steam blanch + 0.3% citric acid for 25 s, B7 – Steam blanch + 0.3% citric acid for 30 s, B8 – Steam blanch + 0.5% citric acid for 20 s, B9 – Steam blanch + 0.5% citric acid for 25 s, B10 – Steam blanch + 0.5% citric acid for 30 s).

Since ΔE resembles the deviation of colour from the original sample before optimization of the pretreatment ΔE was also studied. From the Table 4.2, *ΔE* is increasing with increase in the blanching time and there was a significant increase ($p<0.05$) with increase in blanching time at 100°C. Lower the *ΔE* more closely to the freshness of the sample. In the present study *ΔE* value is lower in the case of samples B2 and B3, but the enzymatic browning was positive in B2 and B3 treatment. So, B4 was considered as the best treatment where enzymatic browning was absent and *ΔE* value was lower compared to other treatments.

The *Chroma* value for the fresh jackfruit sample was 52.90 ± 0.02. The *Chroma* value showed no significant difference ($p<0.05$) for steam blanching as well as steam blanching with citric acid at blanching time of 20 to 30 s. A greater *Chroma* value represents the more pure and intense colour towards the fresh sample by Agnieszka *et al*., (2014). In the present study *Chroma* value is more in the case of B2, B3 and B4 treatments. After considering the results obtained in peroxidase and catalase test along with the colour B4 can be taken as the best treatment over B2 and B3. By observing all the colour parameters like *L, a, b, ΔE* and *Chroma* values, the B4 treatment was selected as the best pretreatment.

ANOVA table for optimization of blanching treatment for ripened deseeded jackfruit bulb is presented in Appendix II.

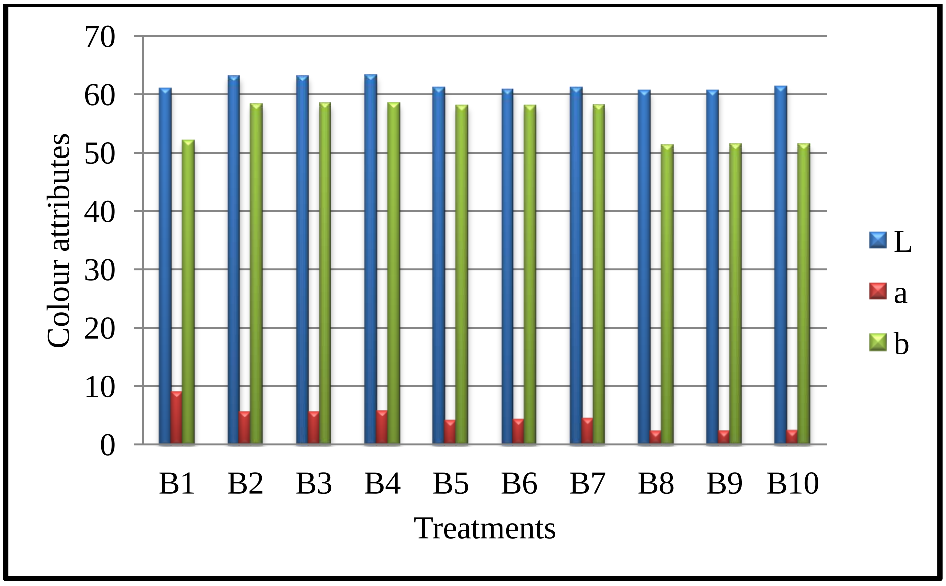

Figure 4.1 – Effect of pre – treatments on colour attributes

4.2.3 Effect of pretreatment on texture attributes

The ripened deseeded jackfruit bulbs were subjected to compression tests in the texture analyzer to estimate the textural characteristics like firmness and toughness. Table 4.3 describes the mean values of firmness and toughness for all the treatments. The firmness (N) and toughness (Ns) values for the fresh ripened deseeded jackfruit bulbs were 4.87 ± 4.60 (N) and 1.57± 1.73 (Ns). From the Figure 4.2 it is clear that both firmness and the toughness increases with increase in blanching time. This is due to the decrease in a_w during steam blanching which makes the sample harder in texture. A similar result was also reported for steam blanched apple slices by Beveridge and Weintraub (1995). ANOVA table for effect of pretreatments on texture attributes is presented in Appendix II.

Table 4.3 – Effect of pretreatments on textural attributes

Treatments	Texture attributes ± SD	
	Firmness (N)	Toughness (Ns)
B1(Control)	4.87±0.80 ^{abc}	1.57±0.91 ^{a}
B2	6.82±1.39 ^{a}	1.34±0.55 ^{a}
B3	6.90±1.43 ^{a}	1.43±0.45 ^{a}
B4	7.03±1.47 ^{a}	1.68±0.45 ^{a}
B5	5.48±0.65 ^{ab}	1.84±0.50 ^{a}
B6	5.71±0.68 ^{ac}	1.99±0.91 ^{a}
B7	5.98±0.70 ^{ab}	2.04±0.86 ^{a}
B8	3.34±1.80^{c}	2.52±0.85 ^{a}
B9	3.52±1.85^{bc}	2.73±1.55 ^{a}
B10	3.73±1.85 ^{bc}	2.99±1.56 ^{a}

The samples treated with citric acid showed the lowest firmness as compare to other treatments. This might be due to the absorption of chemical molecules by the jackfruit tissue. The firmness and toughness in the case of B2 and B3 treatments was on par with B4 treatment and was significantly superior and recorded as group ‘a’. Based on the texture attributes and with the statistical results, B4 was chosen as an appropriate treatment satisfying all the conditions.

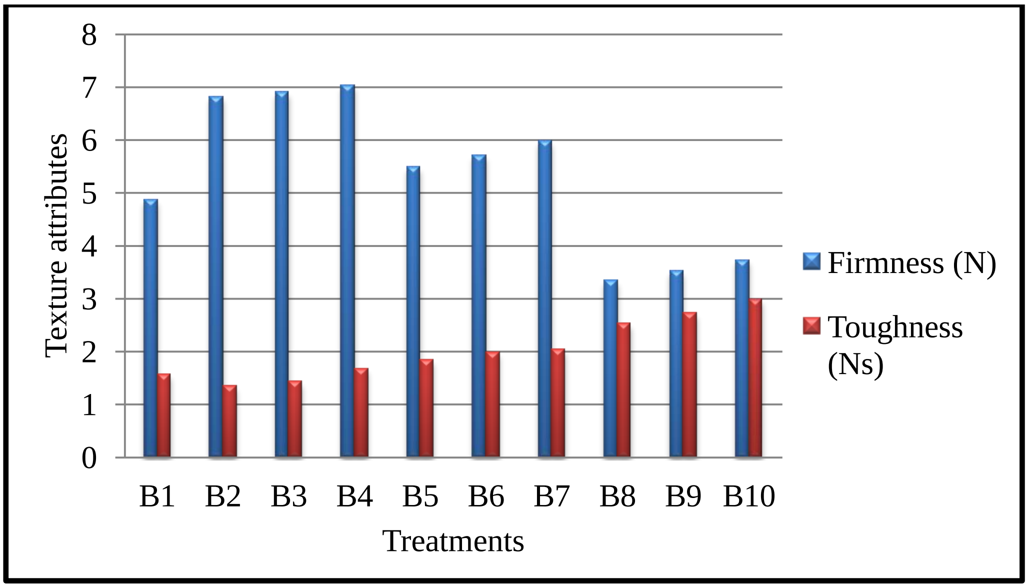

Figure 4.2 – Effect of pre – treatments on texture attributes

Considering all the quality parameters like peroxidase test, catalase test, colour and texture attributes steam blanching at 100°C for 30 s was optimized for as the best pretreatment for further drying studies.

4.3 OPTIMIZATION OF DRYING TEMPERATURE

Vacuum drying is one of the preservative methods to prolong the shelf life of ripened jackfruit bulbs under sub-atmospheric pressures. The lower pressure results in reduced drying temperature and higher quality attributes than classical processes (Jaya and Das, 2003).

The drying studies was carried out only with optimized blanched samples at various vacuum chamber temperatures of 25, 30, 35, 40, and 45°C at vacuum pressure of 680 mm of Hg. The quality parameters such as moisture content, TSS, pH, vitamin C, colour and texture were analyzed for the optimization of drying temperature.

4.3.1 Effect of vacuum drying on moisture content of dried ripened deseeded jackfruit bulbs

The moisture content represents the available water in food products, which predicts the shelf life of the product. Figure 4.3 shows the drying curve of blanched and control sample dried at vacuum chamber temperatures at 25, 30, 35, 40, and 45°C. The drying curve enables an estimation of the time required to reach a stable moisture content which is 4 to 7% for jackfruit (Alok *et al*., 2015). Effect of vacuum drying on moisture content for control and blanched dried ripened deseeded jackfruit bulbs is presented in Appendix III and VI.

The final moisture content of dried ripened deseeded jackfruit bulbs for blanched samples was found to be 7.78 ± 0.03% (d.b.) in case of 25°C, 7.70 ± 0.12% (d.b.) at 30°C, 7.73 ± 0.70% (d.b.) at 35°C, 7.46 ± 0.27% (d.b.) at 40°C and 7.44 ± 1.01% (d.b.) at 45°C. Similarly, the final moisture content for control samples, was found to be 7.83 ± 0.35% (d.b.) at 25°C, 7.60 ± 0.44% (d.b.) at 30°C, 7.56 ± 0.21% (d.b.) at 35°C, 7.50 ±1.07 % (d.b.) at 40°C and 7.48 ± 0.14% (d.b.) at 45°C.

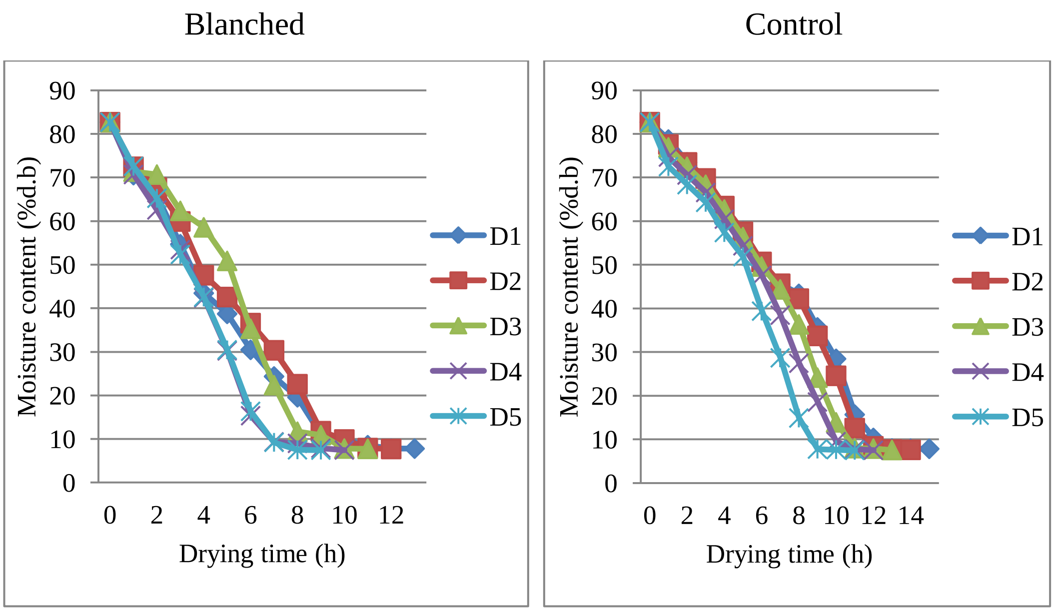

Figure 4.3 – Effect of vacuum drying on moisture content of blanched and control dried ripened deseeded jackfruit bulb

From the Figure 4.3 it shows that as the temperature increases the drying time decreases. At the beginning of the drying process, the moisture removal was high but it declines subsequently due to moisture migration from the inner pores to the surface. Drying curve indicates that, there was no constant rate period in drying and the drying process took place in falling rate period during which internal molecular diffusion is the predominant mechanism of mass transfer.

Higher drying temperature results in greater drying rate. So the highest value of drying rate was observed at vacuum chamber temperature of 45°C. At higher temperatures, the water evaporation rate is greater, influencing the moisture content and subsequently reduces the water activity in the product which enhances the shelf life. The same trend was also reported by Zuniga *et al*., (2006) for drying of jackfruit by using tray drier.

Drying time required to reach the final moisture contents for blanched samples were 13, 12, 11 10 and 9 h. Similarly for control samples were 15, 14, 13, 12 and 11 h. Drying time required to reach the constant moisture level for control sample was more compared to blanched samples. The rapid removal of moisture is due to the softening of the tissues during steam blanching which reduces the time of drying irrespective of temperature. In addition, in the case of control sample, due to the prolonged drying time the shrinkage was noticed which adversely affected the quality.

Plate 4.1 – Control vacuum dried Jackfruit bulbs

Plate 4.2 – Blanched Vacuum dried Jackfruit bulbs

The moisture content of dried ripened deseeded jackfruit bulbs were analysed statistically and showed non significant ($p<0.05$).

4.3.2 Effect of vacuum drying on TSS (°Brix) of dried ripened deseeded jackfruit bulbs

The TSS represents the total soluble solids in the food materials. The initial TSS of the ripened deseeded jackfruit bulbs was found to be 22.26 ± 2.31 °Brix. Figure 4.4 shows the effect of drying temperature on TSS of dried ripened deseeded jackfruit bulbs. From the Figure 4.4, it can be observed that TSS in dried jackfruit bulbs increased with increase in drying temperature for both control as well as blanched samples. This might be due to the reduction in moisture content during drying. ANOVA established the existence of insignificant ($p<0.05$) differences in mean values of the TSS content for dried jackfruit bulbs. The maximum TSS was recorded at sample dried at vacuum chamber temperature of 45°C. The dried sample obtained at 40°C temperature showed on par value with 45°C dried sample. No significant differences were found between pretreated dried jackfruits bulbs from D1 to D5.

Similar results were obtained by Dereje *et al*., (2009) for hot air drying of tomatoes. The study reported that the decrease in moisture content is usually accompanied by an increase in percentage of TSS, since TSS is the major component of dry matter. Also, Martinez *et al*., (2013) reported that during blanching, TSS showed a reduction in the soluble solids, with losses of about 38%, in the case of turnip greens.

Table 4.4 – Effect of vacuum drying on TSS (°Brix) of dried ripened deseeded jackfruit bulbs

Temperature (°C)	TSS (°Brix) ± SD	
	Control	Blanch
25	12.88±0.01^{d}	10.99±0.04^{b}
30	13.78±0.01^{d}	11.59±0.02^{b}
35	15.50±0.04^{bc}	12.16±0.02^{b}
40	15.93±0.03^{ab}	13.04±0.02^{a}
45	16.18±0.01^{a}	13.44±0.02^{a}

Total soluble solids was significantly ($p<0.05$) influenced by linear terms of drying temperature. The vacuum chamber temperatures at 40°C for drying time of 11 h for control and 10 h for blanched samples showed significantly ($p<0.05$)

superior and were recorded as group ‘ab’ and ‘a’. ANOVA table for blanched and control dried ripened deseeded jackfruit bulbs is given in Appendix V and VI.

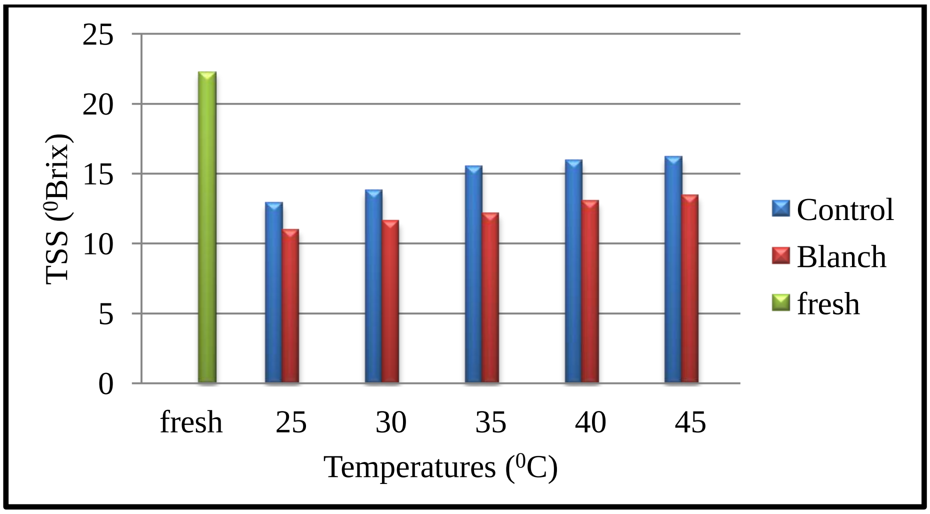

Figure 4.4 – Effect of vacuum drying on TSS (°Brix) of dried ripened deseeded jackfruit bulb

4.3.3 Effect of vacuum drying on pH of dried ripened deseeded jackfruit bulbs

pH represents the logarithmic value of the food materials. A minimum pH value of 5.76 ± 0.01 was obtained for the control sample dried at 25°C and maximum value of 6.62 ± 0.02 was recorded for blanched dried sample at 45°C. This increase in pH value was due to a higher extraction of soluble compounds and also might be loss of organic acids during blanching process. During blanching pH increases due to decrease in acidity and when the same sample is subjected to drying acidity decrease with increase in pH value. This is due to the oxidation process that takes place during drying which increases the pH value. Valdenegro *et al*., (2013) also reported a same trend that the initial pH of the fresh golden berry fruit was 3.54, which increases to 4.58 during drying.

Table 4.5 - Effect of vacuum drying on pH of dried ripened deseeded jackfruit bulbs

Temperature (°C)	pH ± SD	
	Control	Blanch
25	5.76±0.01[cd]	6.15±0.02[ab]
30	5.84±0.01[d]	6.24±0.02[cd]
35	5.93±0.01[b]	6.35±0.02[bc]
40	6.03±0.01[b]	6.50±0.11[ab]
45	6.12±0.02[a]	6.62±0.02[a]

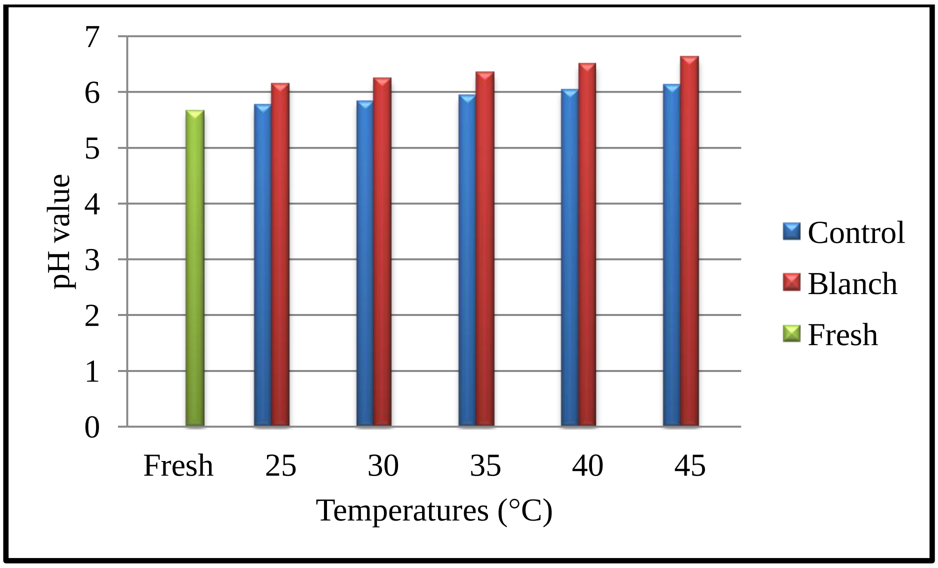

Figure 4.5 – Effect of vacuum drying on pH for dried ripened deseeded jackfruit bulbs

From the figure 4.5, it is shown that insignificant differences ($p<0.05$) occurred between the control dried as well as the blanched dried samples. The control and blanched samples increased significantly ($p<0.05$) with the increase in the drying temperature from 25 to 45°C. The vacuum chamber temperature at

40°C was significantly superior and recorded as group 'b' and 'ab' for dried control and blanched sample. ANOVA table for blanched and control dried ripened deseeded jackfruit bulbs is given in Appendix V and VI.

4.3.4 Effect of vacuum drying on Vitamin C of dried ripened deseeded jackfruit bulbs

The effect of the drying conditions on the degradation of Vitamin C is shown in Table 4.6 and Figure 4.6. A reduction in Vitamin C is observed with an increase in drying temperature. The initial vitamin C of the fresh ripened deseeded jackfruit bulb was of 7.76 ± 0.72 mg/100 g. Control samples showed low vitamin C losses compared to the pretreated jackfruit samples. The lack of major changes in the skin of control samples protected vitamin C from the effects of oxygen during drying which is reported by Carranza *et al*., (2012) for drying of raisins. The decrease in vitamin C of blanched samples compared to control samples is due to the oxidation process during blanching and also during drying process.

Vitamin C is the least stable of all vitamins and it is thermo sensible and that might be the reason of lower value obtained in the blanched sample compared to control sample. Ahmet *et al*., (2010) reported that increase in drying air temperature causes more loss in vitamin C for kiwifruit even after blanching. Seung and Adel, (2000) also reported that blanching reduces the vitamin C content during processing of horticultural crops. ANOVA table for blanched and control dried ripened deseeded jackfruit bulbs is given in Appendix V and VI.

Table 4.6 - Effect of vacuum drying on Vitamin C (mg/100 g) of dried ripened deseeded jackfruit bulbs

Temperature (°C)	Vitamin C (mg/100 g) ± SD	
	Control	Blanch
25	6.47±0.01^{a}	5.59±0.02^{b}
30	6.40±0.10^{ab}	5.56±0.02^{c}
35	6.36±0.01^{b}	5.53±0.03^{b}
40	6.28±0.01^{bc}	5.49±0.02^{b}
45	5.84±0.02^{d}	5.23±0.02^{d}

The higher value of vitamin C content was observed at 25°C for both control as well as blanched samples with value of 6.47 ± 0.01 and 5.59 ± 0.02. On the basis of statistical analysis the blanched as well as control samples showed significant ($p<0.05$) superior quality with group 'bc' and 'b' for samples vacuum dried at 40°C which was considered as the best sample in concern to the other quality attributes.

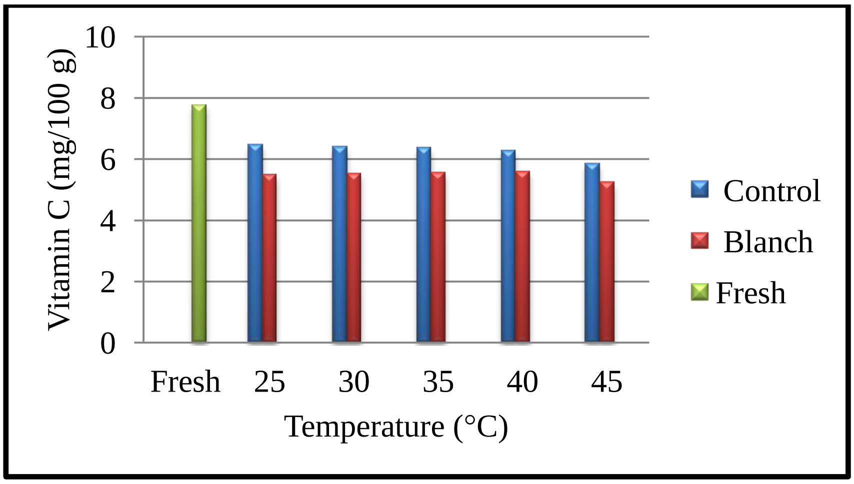

Figure 4.6 – Effect of vacuum drying on vitamin C for dried ripened deseeded jackfruit bulbs.

4.3.5 Effect of vacuum drying on the colour parameters of dried deseeded jackfruit bulbs

The first judgment of a food's quality is dependent on its appearances and characteristics such as colour, surface structure and shape. Colour, in particular, is an important sensory attribute (Brimelow and Groesbeck, 1993). The *L*, *a* and *b* uniform colour space is based on the CIE system. *L* defines lightness, *a* denotes the red to green and *b* represents the blue to yellow colour value. A dark product is usually unappealing to the consumer as it indicates over processing. Total colour change (ΔE) and *Chroma* was also determined to evaluate the colour change during drying.

4.3.5.1 Effect of vacuum drying on colour (L value) of dried ripened deseeded jackfruit bulbs

The initial *L* value of the ripened deseeded jackfruit bulbs was found to be of 61.03 ± 1.18. From the Figure 4.7, the colour of the blanched sample was much lighter (higher *L* value) than the control sample irrespective of vacuum drying temperature. ANOVA table for blanched and control dried ripened deseeded jackfruit bulbs is given in Appendix V and VI.

Table 4.7 - Effect of vacuum drying on colour *L* value of dried ripened deseeded jackfruit bulbs.

Temperature (°C)	*L* value ± SD	
	Control sample	Blanched sample
25	28.61 ± 0.10^{b}	42.73 ± 0.03^{a}
30	28.66 ± 0.10^{a}	42.70 ± 0.04^{b}
35	28.97 ± 0.01^{ab}	42.60 ± 0.02^{bc}
40	30.42 ± 0.01^{ac}	42.58 ± 0.01^{b}
45	37.01 ± 0.02^{c}	42.50 ± 0.01^{d}

From the Table 4.7, it is shown that as the drying temperature increases *L* value also increases. This might be due to the moisture loss and the non-enzymatic (Millard) browning initiated during drying. A similar trend was reported by Chistensen and Peacock (1997) for dried raisins. The interactions between the drying treatments on colour *L* values of dried ripened deseeded jackfruit bulbs was analyzed statistically at ($p<0.05$), and is presented in Appendix III. A significant difference in colour *L* values between control and blanched samples was observed and control samples were darker in colour than blanched samples due to decrease in the *L* value. Hence drying at 40°C gave better colour product than other temperature in accordance with the other quality parameters.

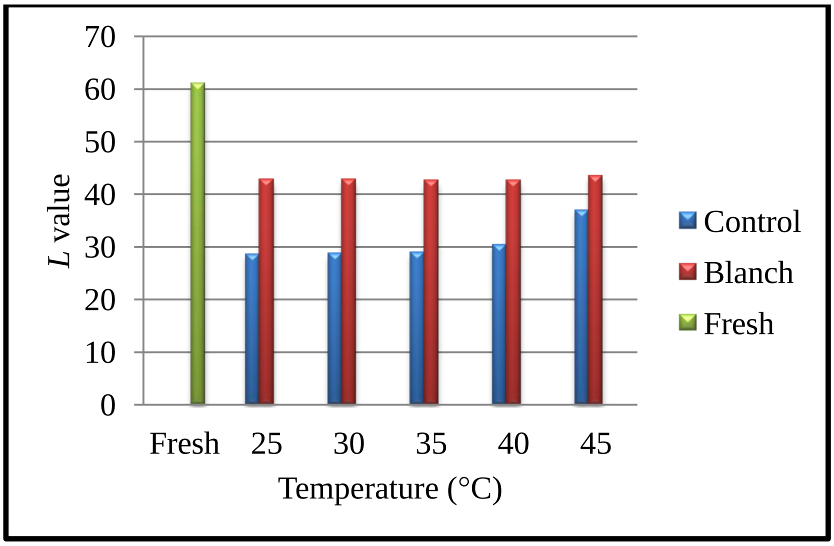

Figure 4.7 – Effect of vacuum drying on colour *L* value for dried ripened deseeded jackfruit bulbs

4.3.5.2 Effect of vacuum drying on colour (a value) of dried ripened deseeded jackfruit bulbs

The effect of drying on *a* value of vacuum dried ripened deseeded jackfruit bulbs is presented in Table 4.8 and the graphical representation is given in Figure 4.8. The colour *a* value of fresh sample was evaluated as 8.89 ± 0.80. From the Table 4.8 it is observed that *a* value increases with a range from 10.55 ± 0.02 to 18.64 ± 0.02 for control samples and 12.41 ± 0.02 to 19.58 ± 0.02 for blanched samples. Maximum *a* value was observed for blanched sample dried at 45°C and minimum for control sample dried at 25°C. As the drying temperature increases *a* value also increases for both control and blanched samples. This increase indicates that the dried sample is more reddish in colour and this may be due to carotenoid degradation and non-enzymatic browning. A similar result was reported by Akoy (2014) for drying of mango slices. ANOVA table for blanched and control dried ripened deseeded jackfruit bulbs is given in Appendix V and VI. From the ANOVA, an increase in colour *a* value showed insignificant at ($p<0.05$) level of significance

Table 4.8 - Effect of vacuum drying on colour *a* value of dried ripened deseeded jackfruit bulbs

Temperature (°C)	*a* value ± SD	
	Control	Blanch
25	10.55±0.02[c]	12.41±0.02[d]
30	12.35±0.04[c]	15.26±0.03[a]
35	12.56±0.03[b]	15.33±0.02[b]
40	13.35±0.03[b]	16.66±0.03[ab]
45	18.64±0.02[a]	19.58±0.02[a]

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The drying temperature at 40°C with drying time of 11 and 10 h was significantly superior and recorded as group 'b' and 'ab' for control and blanched sample.

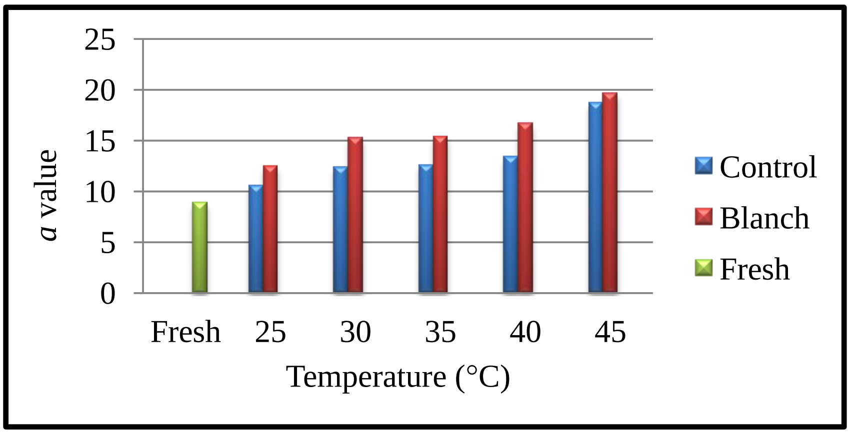

Figure 4.8 – Effect of vacuum drying on *a* value for dried ripened deseeded jackfruit bulbs

4.3.5.3 Effect of vacuum drying on colour (b value) of dried ripened deseeded jackfruit bulbs

The effect of vacuum drying on *b* value of ripened deseeded jackfruit bulbs is presented in Table 4.9 and Figure 4.9. The table 4.9 revealed that colour *b* value increases with increase in drying temperature from 18.05 ± 0.03 to 24.18 ± 0.05 and 22.04 ± 0.03 to 30.73 ± 0.02 for control and blanched samples respectively. The initial *b* value of fresh tender jackfruit was recorded as 52.15 ± 0.91. The relative visual yellow colour parameter (*b* value) increased during drying under various treatments and it might be due to the carotenoid isomerization which leads to the loss of yellowness. The colour pigments may be auto-oxidized by the reaction with atmospheric oxygen and the rates depend on the intensity of oxygen, light and heat. A similar result was reported by Swittra *et al.*, (2001) for vacuum dried durian chips.

Table 4.9 - Effect of vacuum drying on colour *b* value of dried ripened deseeded jackfruit bulbs

Temperature (°C)	*b* value ± SD	
	Control	Blanch
25	18.05 ± 0.03^{a}	22.04 ± 0.03^{a}
30	19.41 ± 0.02^{ab}	26.10 ± 0.05^{a}
35	20.62 ± 0.03^{ab}	26.53 ± 0.04^{a}
40	22.74 ± 0.02^{ab}	27.21 ± 0.03^{b}
45	24.18 ± 0.05^{b}	30.73 ± 0.02^{b}

The interactions between drying treatments on *b* values of vacuum dried ripened deseeded jackfruit bulbs were analyzed statistically. ANOVA table for blanched and control dried ripened deseeded jackfruit bulbs is given in Appendix V and VI. ANOVA for the differential response of the control and blanched dried jackfruit bulbs at various vacuum chamber temperatures showed in significant effect on colour *b* values at ($p<0.05$) significance level.

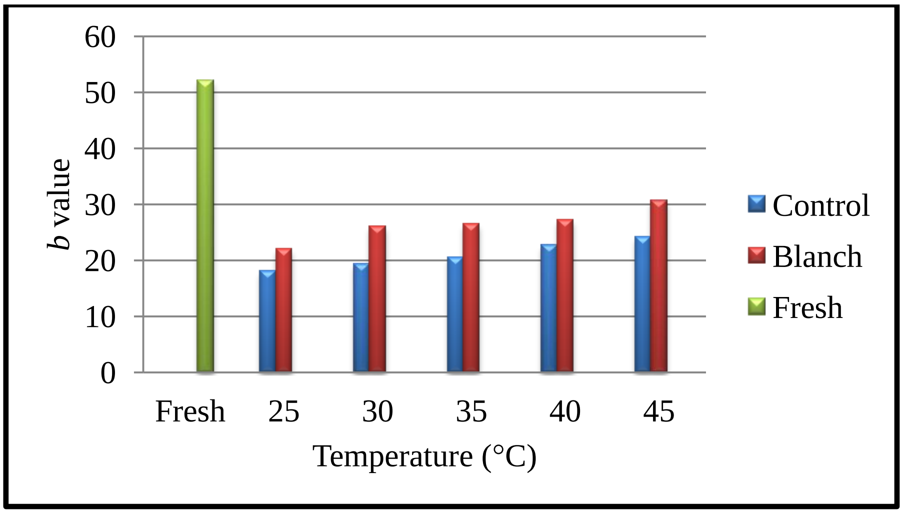

Figure 4.9 – Effect of vacuum drying on colour *b* value for dried ripened deseeded jackfruit bulbs

4.3.5.4 Effect of vacuum drying on L, a, b, ΔE and Chroma of dried ripened deseeded jackfruit bulbs

Effect of vacuum drying on *L, a, b, ΔE* and *Chroma* for control and blanched samples were also estimated for dried ripened deseeded jackfruit bulbs and are presented in Table 4.10(a) and 4.10(b). The total color change (*ΔE*), which is a combination of parameters *L, a* and *b* values, which is a colorimetric parameter extensively used to characterize the variation of colors with respect to the original sample. From the Figure 4.10 it is observed that as the temperature increases the colour parameters (*L, a, b*) increases and shows a decreasing trend in the total colour change (*ΔE)*. The total colour change is influenced by the non enzymatic browning and pigment destruction. The *ΔE* value showed a significant decrease with increase in the drying temperature. In the present study, the least deviation (minimum *ΔE*) value was obtained for the blanched sample dried at 40°C which resembles in the quality characteristics as that of the fresh sample.

The *Chroma* values for control and blanched sample increased with increase in drying temperature. Most desirable product represented by its highest *Chroma* value. From the Table 4.10(b), it is clear that *Chroma* value was higher for the sample dried at 45°C followed by the sample at 40°C. But *ΔE* value was lower at

40°C. So, considering both *ΔE* and *Chroma* value, drying temperature at 40°C is considered as the better treatment.

Table.4.10 (a) Effect of vacuum drying on *L, a, b, ΔE* and *Chroma* of control dried ripened deseeded jackfruit bulbs

Temperature (°C)	*L*	*a*	*b*	*ΔE*	*Chroma*
25	28.61^{b}	10.55^{c}	18.05^{a}	47.08 ± 0.04^{c}	20.90^{b}
30	28.66^{a}	12.35^{c}	19.41^{ab}	46.17 ± 0.01^{c}	23.00^{b}
35	28.97^{ab}	12.56^{b}	20.62^{ab}	45.11 ± 0.01^{c}	24.14^{b}
40	30.42^{b}	13.24^{b}	22.74^{ab}	42.68 ± 0.04^{a}	26.31^{a}
45	30.40^{d}	13.20^{a}	22.70^{b}	42.70 ± 0.02^{b}	26.25^{a}

Table.4.10 (b) Effect of vacuum drying on *L, a, b, ΔE* and *Chroma* of blanched dried ripened deseeded jackfruit bulbs

Temperatures (°C)	*L*	*a*	*b*	*ΔE*	*Chroma*
25	42.73^{a}	12.41^{d}	22.04^{a}	$35.41\ \pm0.11^{a}$	25.29^{a}
30	42.70^{b}	15.56^{a}	26.10^{a}	32.48 ± 0.06^{a}	30.38^{b}
35	42.60^{bc}	15.33^{b}	26.53^{a}	32.21 ± 0.20^{a}	30.46^{b}
40	42.58^{b}	16.66^{ab}	27.21^{b}	31.98 ± 0.50^{b}	32.59^{b}
45	42.60^{c}	15.15^{a}	26.54^{b}	32.43 ± 0.01^{b}	34.09^{c}

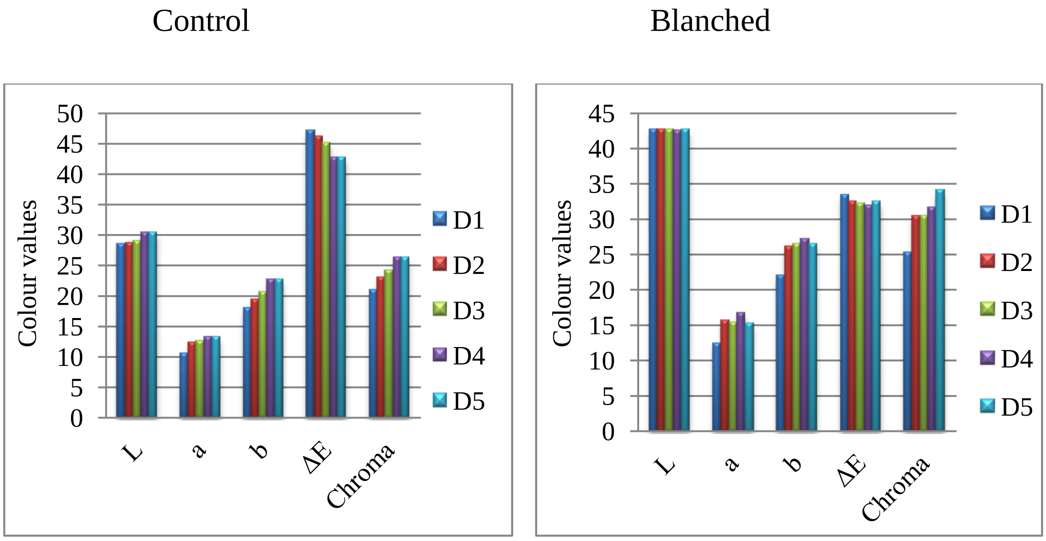

Figure 4.10 – Effect of vacuum drying on *L, a, b, ΔE* and *Chroma* of control and blanched dried ripened deseeded jackfruit bulbs

4.3.6 Effect of vacuum drying on texture attributes of dried ripened deseeded jackfruit bulbs

Texture indicates the hardness of the sample after drying. The firmness (N) and toughness (Ns) are the two textural quality parameters which were examined to optimize the force required to rupture the dried jackfruit sample. The firmness and toughness of dried jackfruit bulbs are discussed below.

4.3.6.1 Effect of vacuum drying on firmness of dried ripened deseeded jackfruit bulbs

The effect of vacuum drying on firmness of vacuum dried ripened deseeded jackfruit bulbs is shown in Table 4.11. As the temperature increases firmness also increases. During drying the liquid diffuses and carries solutes to the surface of jackfruit bulbs from interior. As the surface moisture evaporates, solutes concentrate and leave a hard and dry skin which resulted case hardening. A similar result was found by Shan and Nath, (2008) for vacuum drying of litchis. From the ANOVA, it is observed that the firmness values was in significant ($p<0.05$) with increase in drying temperature. A maximum firmness value was observed as 36.20 ± 0.03 for blanched sample dried at 45°C.

Table 4.11 - Effect of vacuum drying on firmness of dried ripened deseeded jackfruit bulbs

Temperature (°C)	Firmness (N)	
	Control	Blanch
25	21.85±0.02[a]	32.18±0.02[b]
30	28.16±0.03[b]	33.21±0.02[ab]
35	29.26±0.02[a]	34.53±0.02[ab]
40	30.81±0.02[b]	34.80±0.02[bc]
45	32.04±0.04[b]	36.20±0.03[bc]

ANOVA table for blanched and control dried ripened deseeded jackfruit bulbs is given in Appendix V and VI. From the statistical analysis, the samples dried at 40°C and 45°C showed superior quality with group ‘b’ and ‘bc’ for control and blanched samples. The groups showing ‘a, b, c’ are accepted as the superior treatments. Considering all the other quality parameters, the sample dried at a vacuum temperature of 40°C was standardized as better treatment in terms of firmness.

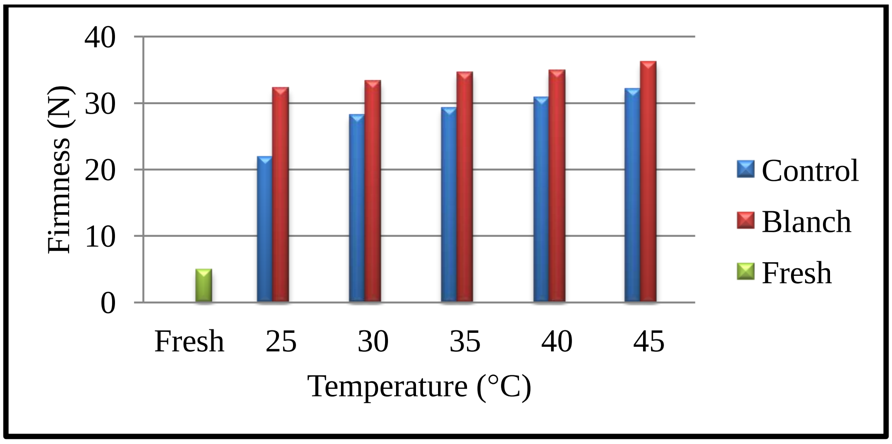

Figure 4.11 – Effect of vacuum drying on firmness (N) for dried ripened deseeded jackfruit bulbs

4.3.6.2 Effect of vacuum drying on toughness of dried ripened deseeded jackfruit bulbs

The effect of vacuum drying on toughness of dried ripened deseeded jackfruit bulbs are furnished in Table 4.12 and graphical representation in Figure 4.12. The table revealed that the toughness was increased with increase in drying temperature for both control and blanched samples. The higher value of toughness in the blanched samples than control samples is due to the development of case hardening during drying. The higher the moisture content the lesser the case hardening. In the case of blanched sample case hardening is more, because of less water content which makes the product harder resulting tougher in nature.

Table 4.12 - Effect of vacuum drying on toughness of dried ripened deseeded jackfruit bulbs

Temperature (°C)	Toughness (Ns)	
	Control sample	Blanched sample
25	4.81 ± 0.02^{b}	6.69 ± 0.02^{a}
30	6.45 ± 0.02^{b}	7.51 ± 0.03^{a}
35	8.13 ± 0.02^{a}	9.68 ± 0.01^{a}
40	8.94 ± 0.03^{a}	10.57 ± 0.02^{a}
45	9.71 ± 0.03^{a}	12.26 ± 0.06^{a}

A similar result was obtained by Swittra *et al*., (2011) for microwave vacuum dried durian fruit chips. ANOVA table for blanched and control dried ripened deseeded jackfruit bulbs is given in Appendix V and VI.

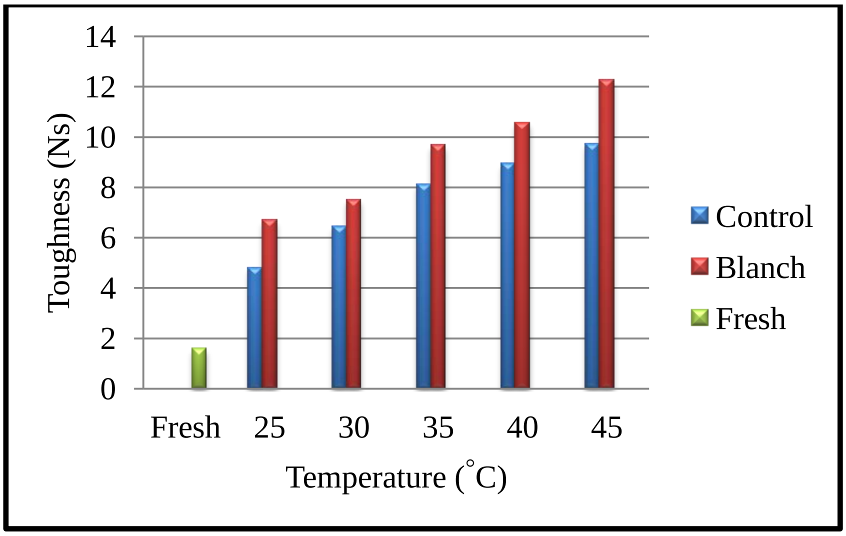

Figure 4.12 – Effect of vacuum drying on toughness of dried ripened deseeded jackfruit bulbs

4.3.7 Effect of vacuum drying on rehydration ratio of dried ripened deseeded jackfruit bulbs

The effect of drying on rehydration ratio of vacuum dried ripened deseeded jackfruit bulbs is presented in Table 4.13 and graphically represented in Figure 4.13. The control samples showed lower rehydration ratio due to their compact tissue structure formed upon drying. The rehydration ratio of dried jackfruit bulbs was found to be maximum at 45°C of 2.70 ± 0.07 for blanched sample and minimum was found at 25°C of 2.20 ± 0.10 for control sample. In general, as the drying time increased, the samples resulted in shrinkage which may be the reason for the lower rehydration ratio. Prevention of tissue collapse at the surface in the case of blanched sample could result in higher rehydration ratio. ANOVA table for blanched and control dried ripened deseeded jackfruit bulbs is given in Appendix V and VI.

Reis *et al*., (2006) stated that higher the rehydration ratio, the higher is the recovery of the original structure in the final product. In the present study, the rehydration ratio increased significantly ($p<0.05$) with increase in the drying temperature for control and blanched samples. The blanched samples dried at 40°C and 45°C showed a higher rehydration ratio. By the statistical analysis the blanched samples dried at 40°C were recorded as group ‘ab’ which was considered as the best treatment in accordance with the other quality attributes. Similar results were reported by Felipe *et al.*, (2012) and Alok *et al.*, (2015) for vacuum drying of yacon slices and drying of jackfruit.

Table 4.13 – Effect of vacuum drying on rehydration ration for vacuum dried ripened deseeded jackfruit bulbs

Temperature (°C)	Rehydration ratio	
	Control	Blanch
25	2.20±0.10^{b}	2.50±0.10^{b}
30	2.33±0.10^{b}	2.56±0.01^{b}
35	2.45±0.10^{a}	2.60±0.01^{b}
40	2.50±0.15^{a}	2.65±0.10^{ab}
45	2.60±0.10^{a}	2.70±0.07^{b}

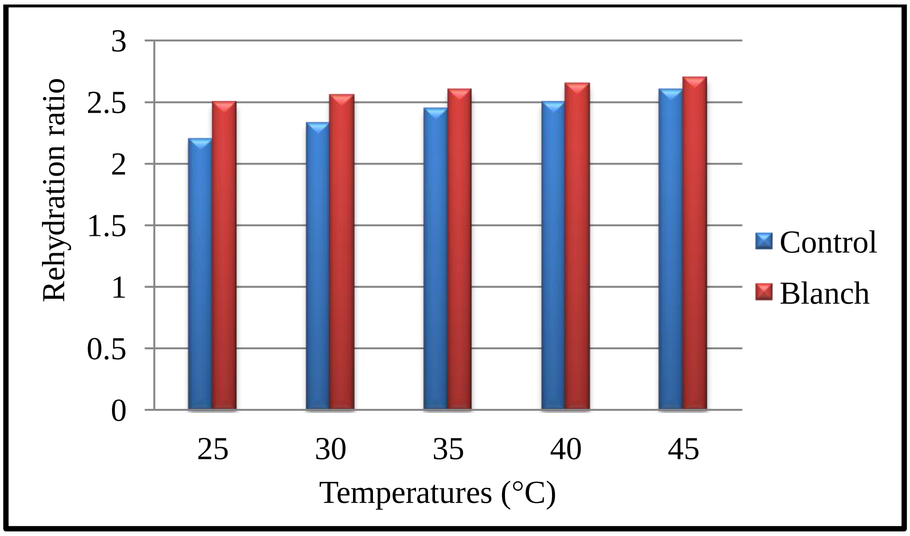

Figure 4.13 – Effect of vacuum drying on rehydration ratio of dried ripened deseeded jackfruit bulbs

Control Blanched

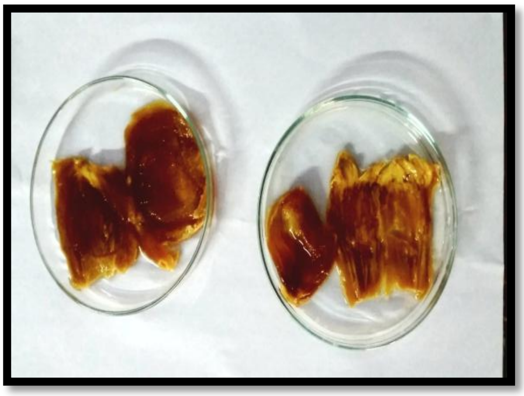

Plate 4.3 – Rehydrated control sample   Plate 4.4 – Rehydrated blanched sample

The combined results of all the quality parameters suggested that steam blanching for 30s followed by vacuum drying at 40°C at a constant vacuum pressure of 680 mm of Hg for 10 h drying time may be used as an optimum drying condition for ripened deseeded jackfruit bulbs.

4.4 STORAGE STUDIES OF THE VACUUM DRIED RIPENED DESEEDED JACKFRUIT BULBS

The storage studies were carried out using five different packaging materials i.e., P1 - Polythene cover, P2 - LDPE – 100 gauge, P3 - LDPE – 300 gauge, P4 - LDPE – 400 gauge and P5 - Laminated Aluminum Foil. The five packaging materials were incorporated with MAP technique in order to increase the shelf life of the processed dried jackfruit bulbs. Studies have shown that modified atmosphere packaging (MAP) have the ability to delay quality loses and thus extends the shelf life of fresh or minimally processed fruits. Modified atmosphere packaging (MAP) techniques in terms of low O_2 and high CO_2 levels, have also been proven to be beneficial in maintaining the quality of various fresh-cut fruits and vegetables (Alasalvar *et al.*, 2005 and Oms *et al.*, 2008).In this study, MAP consisted of 3 kPa O_2 + 5 kPa CO_2 (with balance of N_2) or 30% O_2 + 50% CO_2 gas mixture was flushed to low density polyethylene (LDPE) bags, polythene cover and laminated aluminum foil.

4.5 EFFECT OF PACKAGING AND STORAGE ON MICROBIAL LOAD

The microbial profile with respect to standard plate count (SPC) is presented in Table 4.15 for the different packaging materials under MAP condition during storage. Blanched samples showed control over the SPC compared to the control samples. Gas mixture flushed in packaging materials caused a higher control with lesser microbial growth which was reported by Alok *et al*., (2008) for jackfruit bulbs. The microbial count in P4 treatment was within the permissible limit (not more than 50/g) prescribed by PFA, 1956. The low O_2 and high CO_2 atmosphere restrict the standard plate count for microbial studies by (Bai *et al*., 2001) for honeydew cubes. The MAP condition was helpful in reducing the SPC counts of bacterial organisms. ANOVA table for microbial count on storage from 0 – 30th day for dried ripe jackfruit bulbs is presented in Appendix VII.

Table 4.14 – Microbial analysis of processed vacuum dried ripened deseeded jackfruit bulbs

Treatments	Bacteria (cfu/g) 10^5 dilution					
	Days of storage					
	0		15		30	
	Control	Blanched	Control	Blanched	Control	Blanched
P1	5.1±0.15^b	4.5±0.10^a	9.6±0.10^b	9.2±0.10^c	50±1.52^b	44±2.00^b
P2	4.2±0.05^a	3.8±0.15^b	12.0±0.17^a	11.6±0.10^a	63±1.52^a	52±2.00^a
P3	2.2±0.10^c	1.9±0.10^d	7.7±0.15^c	7.3±0.15^c	39±2.08^c	26±2.00^d
P4	2.0±0.15^a	1.5±0.10^c	7.0±0.15^b	6.7±0.10^b	28±1.00^c	21±1.52^c
P5	2.5±1.24^c	2.0±0.20^d	2.9±0.10^d	11.7±0.15^a	45±2.00^d	38±1.52^e

At the end of 30th day, microbial count was found to be least for the sample stored in P4 (LDPE 400 gauge) treatments from the initial to 30 days. Thus LDPE 400 gauge was found to be the best packaging material for storage of ripened deseeded jackfruit bulbs.

4.6 EFFECT OF PACKAGING MATERIAL AND STORAGE ON QUALITY PARAMETERS

The quality of the dried jackfruit bulbs packed in five different packaging materials and stored at room temperature (28±2°C) was analysed in an interval of 15 days, in order to standardize the suitable packaging material to increases the shelf life of dried ripened deseeded jackfruit bulbs.

4.6.1 Effect of packaging material and storage on moisture content

The variation in moisture content of dried ripened deseeded jackfruit bulbs during storage is graphically shown in Figure 4.14. The moisture content of dried jackfruit bulbs packed in different materials was increased due to migration of water vapour from storage environment into the packaging material. In the present study, P4 packaging material resulted in less moisture absorption which is due to lower water vapour transmission rate observed in (LDPE 400 gauge) when compare to other packaging materials. Thus P4 treatment was selected as best packaging treatment which showed insignificant ($p<0.05$) difference with decrease in moisture content.

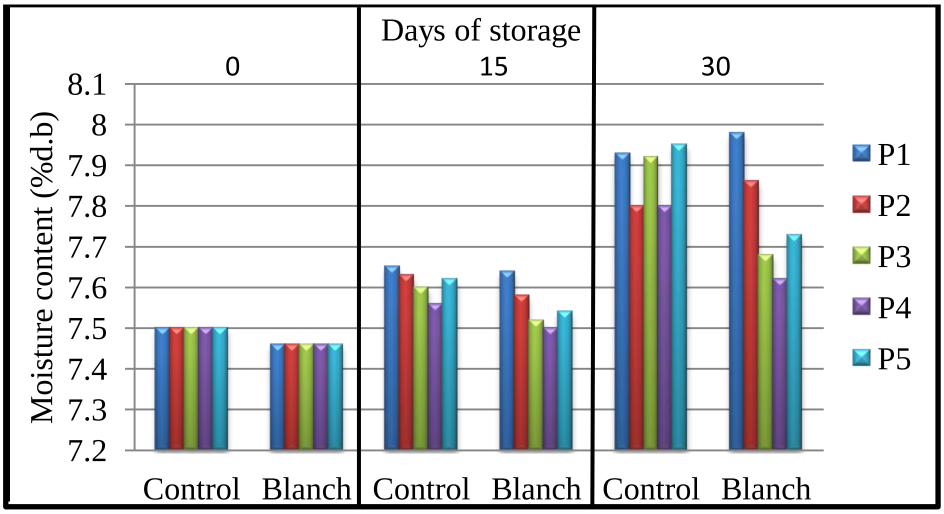

Figure 4.14 – Effect of packaging material and storage on moisture content

ANOVA for moisture content indicate that storage period, temperature, relative humidity and type of packaging materials significantly ($p<0.05$) affect the quality of dried jackfruit bulbs by gaining moisture from storage environment.

During the storage period all the treatments showed a significant ($p<0.05$) increase in the moisture content. The mean values of moisture content during storage is presented in Appendix VIII (a)

4.6.2 Effect of packaging material and storage on TSS (°Brix)

The TSS (°Brix) of dried ripened deseeded jackfruit bulbs are shown in the Figure 4.15. The TSS content showed only decimal changes during the first 15 days of storage, but slight decrease was observed in further storage period. This decrease during storage is due to utilization of sugars by growth of microbes. From the Table 4.16, it is clear that insignificant ($p<0.05$) difference was observed in P4 treatment which showed less loss of TSS content during storage period.

Decrease in total sugars in dried jackfruit bulbs is due to increase in reducing sugars by acid hydrolysis of total and non-reducing sugars reported by Mir and Nath, 1993: Rao and Roy, 1980: Meyer 1966; Roy and Singh 1979. In the present study, the P4 treatment was on par with P1, P2, P3 and P5 treatment for blanched samples. Considering all the treatments, P4 treatment showed a lower degradation in TSS content which was selected as the best packaging treatment to increase the shelf life of dried jackfruit bulbs. The mean values of TSS (°Brix) during storage are presented in Appendix VIII (b).

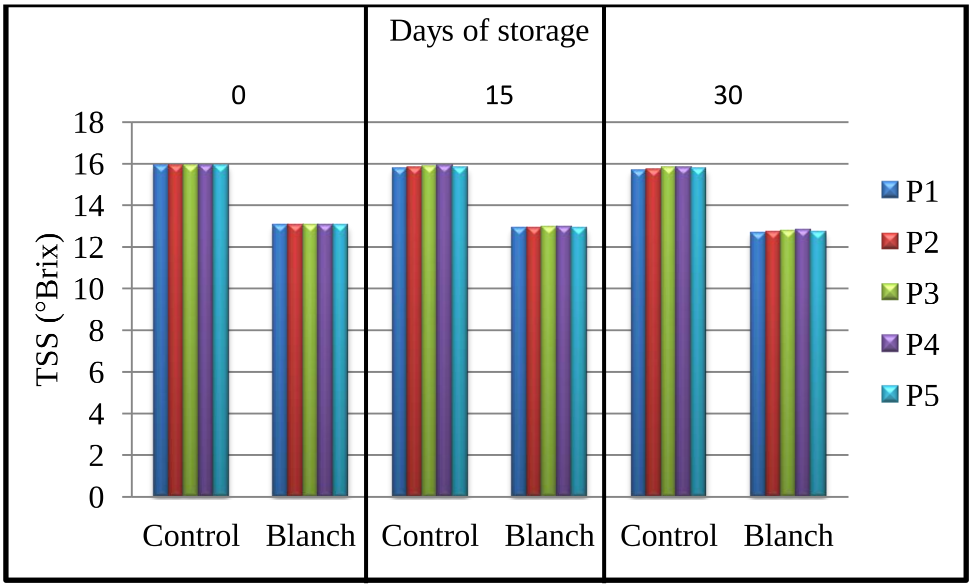

Figure 4.15 – Effect of packaging material and storage on TSS(°Brix)

4.6.3 Effect of packaging material and storage on pH

Measurement of pH is an index for determining food quality especially during storage. The variation in pH value of dried ripened deseeded jackfruit bulbs were shown in Figure 4.16. pH value is decreased due to increase in acidity during storage period. Insignificantly ($p<0.05$) difference was observed in all the treatments. Similar results on reduction in pH value during storage of processed litchis were obtained by Shah and Nath (2008). The statistical analysis observed that storage intervals and treatments showed a significant ($p< 0.05$) decrease in pH value of dried jackfruit bulbs during storage. Less loss of pH value was observed in P4 treatment which showed insignificant ($p<0.05$) difference during storage intervals. The mean values of pH during storage are presented in Appendix VIII (c).

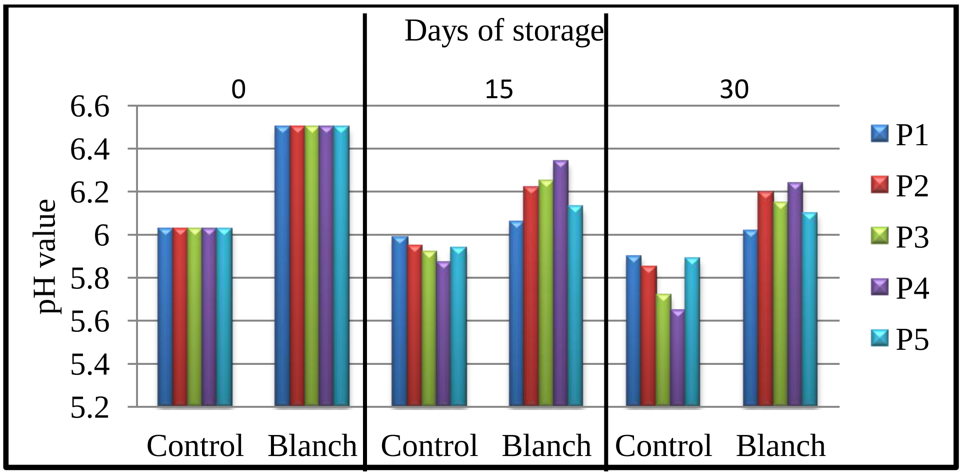

Figure 4.16 – Effect of packaging material and storage on pH

4.6.4 Effect of packaging material and storage on Vitamin C

The effect of packaging and storage on vitamin C is graphically represented in Figure 4.16. An insignificant ($p<0.05$) decrease in vitamin C was observed between the packaging treatments. The sample stored in P3, P4 and P5 resulted in less loss of vitamin C. This is due to lower respiratory activity which retained higher vitamin C in MA packed sample which was reported by Alok *et al.*, (2009). The mean values of vitamin C during storage are presented in Appendix VIII (d).

At the end of 30 days, the P4 treatment was found to be superior as it retards oxidation process during storage. Vitamin C of P4 treatment was 6.47 ± 0.03 for control and 5.48 ± 0.03 mg/100 g for blanched samples. Results showed that samples P2, P3, P5 of control and P2, P3, P5 of blanched samples retains maximum amount of vitamin C. The minimum mean values were recorded in sample P2 of 6.18 ± 0.01 for control and P5 of 5.46 ± 0.01 for blanched sample mg/100 g. The maximum restriction in loss was found in case of P4 treatment, due to effective low O_2 atmosphere generated within the package, followed by other treatments (Alok *et al.*, 2009) i.e., P1, P2, P3 and P5. So, P4 treatment was considered as the best treatment for dried jackfruit bulbs during storage. Gimnez *et al.*, (2003) reported that the loss of vitamin C has been attributed to its reactivity to O_2 and its degradation has been associated with non enzymatic browning for storage of borage fruit.

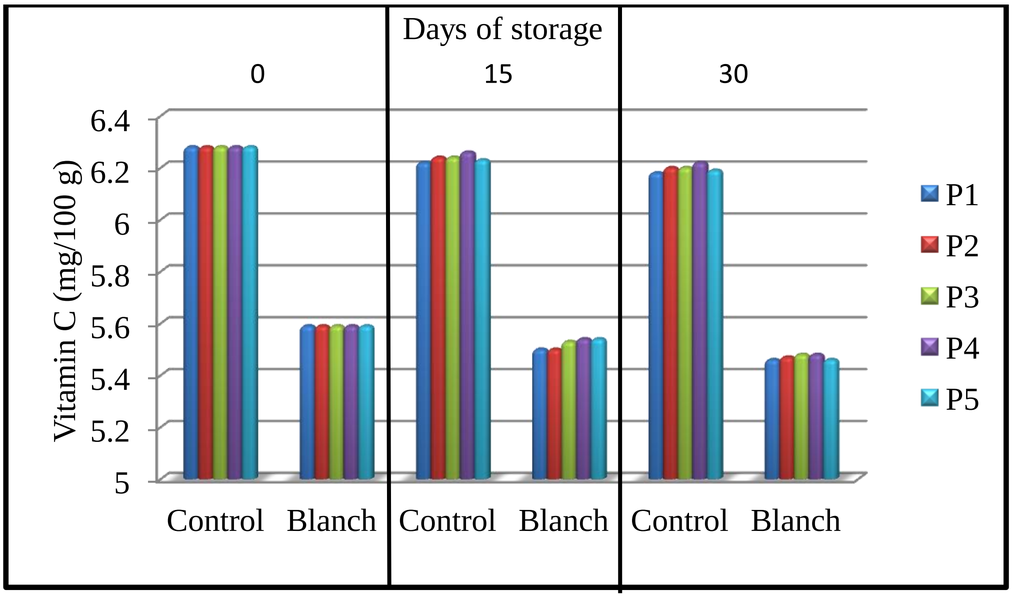

Figure 4.17 – Effect of packaging material and storage on vitamin C.

4.6.5 Effect of packaging material and storage on colour attributes

The golden yellowish color of jackfruit bulb is usually a major factor in consumer preference. In the present study, the internal gas composition present in different MA packages during storage studies significantly ($p<0.05$) affected the color parameters of dried jackfruit bulb (Saxena *et al.*, 2008).

4.6.5.1 Effect of packaging material and storage on colour L value (black – white)

The *L* value of dehydrated jackfruit bulbs obtained for different packaging treatments are discussed in Table 4.19 and represented in Figure 4.18. The *L* value of fresh ripened deseeded jackfruit bulb is 61.03 ± 1.18. The colour *L* value decreases due to increase in storage period. A significant ($p< 0.05$) difference was observed within the packaging material for dried jackfruit bulbs during storage. The pronounced decrease in *L* value of control MAP sample indicated darkening of jackfruit bulbs tissue, which could be attributed to the skin browning of the fruit surface due to oxidation of polyphenols and formation of dark pigment reported by Cia *et al*., (2006) and Cocci *et al*., (2006). The mean values of colour *L* value during storage are presented in Appendix VIII (e).

From the Figure 4.18, it is clear that the rate of decrease in *L* value showed minimum loss in P4 treatment (LDPE 400 gauge) and maximum loss in P5 treatment (aluminum foil). Decrease in *L* value indicates the browning action during storage. The interaction involving the use of respiratory retardant in blanched sample followed by an effective MAP with low equilibrated O_2 concentration in P4 treatment facilitate maximum retention in colour quality in terms of *L* value. This could be due to higher retention of carotenoids and lesser extent of enzymatic browning caused by retardation in respiration of dried jackfruit bulbs. The maximum *L* value was found in P4 treatment of 40.52 ± 0.02 and minimum of 35.46 ± 0.03 in P5 treatment for blanched sample. Similarly maximum *L* value was found in P4 treatment of 25.56 ± 0.01 and minimum of 23.67 ± 0.01 in P2 treatment for control sample. So, comparing the effect of all the packaging materials used for storage studies, the best was observed in P4 treatment due to lower reduction rate of colour *L* value.

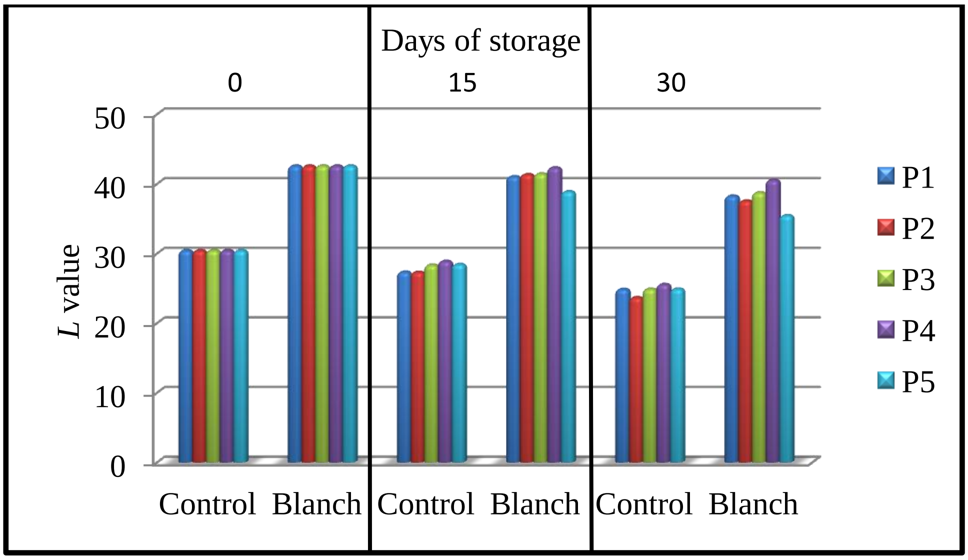

Figure 4.18 – Effect of packaging material and storage on colour *L* value

4.6.5.2 Effect of packaging material and storage on colour a value (green – redness)

The initial value *a* value of fresh ripened deseeded jackfruit bulb was noted as 8.89 ± 0.80. The colour *a* value of dried ripened deseeded jackfruit bulbs in different packaging materials are shown in the Table 4.20 and graphically represented in Figure 4.19 .The statistical analysis showed that colour *a* value increases with the increase in the storage period. The maximum *a* value was observed in P2 treatment of 18.87 ± 0.02 and minimum was found in P4 treatment of 18.67±0.02 for control sample. LDPE bags maintained the color intensity insignificantly ($p<0.05$) for pretreated samples due to lower oxygen level which prevented oxidative browning. The higher retention of carotenoids and lesser extent of enzymatic browning caused by retardation in respiration developed higher a value during storage. The P4 treatment was selected to be superior in maintaining the colour *a* value though out the storage period. The mean values of colour *a* value during storage are presented in Appendix VIII (f).

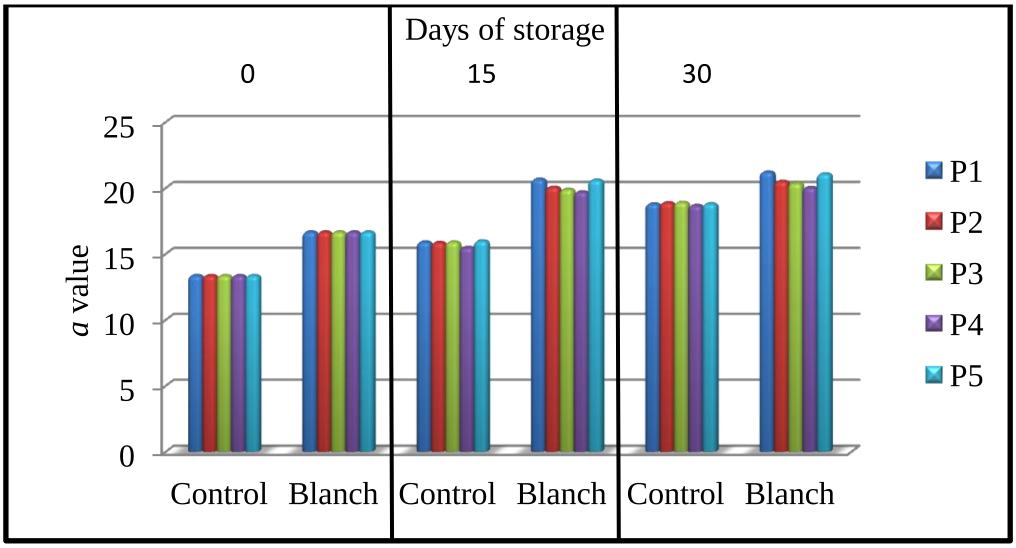

Figure 4.19 – Effect of packaging material and storage on colour *a* value

4.6.5.3 Effect of packaging material and storage on colour b value (blue – yellow)

The colour *b* value i.e., yellowish color of jackfruit bulb is usually a major factor in consumer preference. The effect of different packaging materials and storage of dried jackfruit bulbs on colour *b* value is represented in the Table 4.21 and graphically represented in Figure 4.20. A reduction in *b* value was noticed during storage. The low O_2 content generated by the MA conditions synergized with the pretreatment, causing higher retention of carotenoid. In the present study, the dried jackfruit bulbs was significantly ($p<0.05$) affected by the internal gas composition of MAP packaging materials. Among all the treatments, P4 and P3 treatment (LDPE bags) gave the maximum retention of *b* value significantly for both blanched and control samples followed by P5 treatment (laminated aluminum foil) and P1 treatment (polythene cover). The higher efficiency in LDPE bags is due to anti-respiratory activity with lower oxygen level equilibrated inside the packaging bags. The mean values of colour *b* value during storage are presented in Appendix VIII (g).

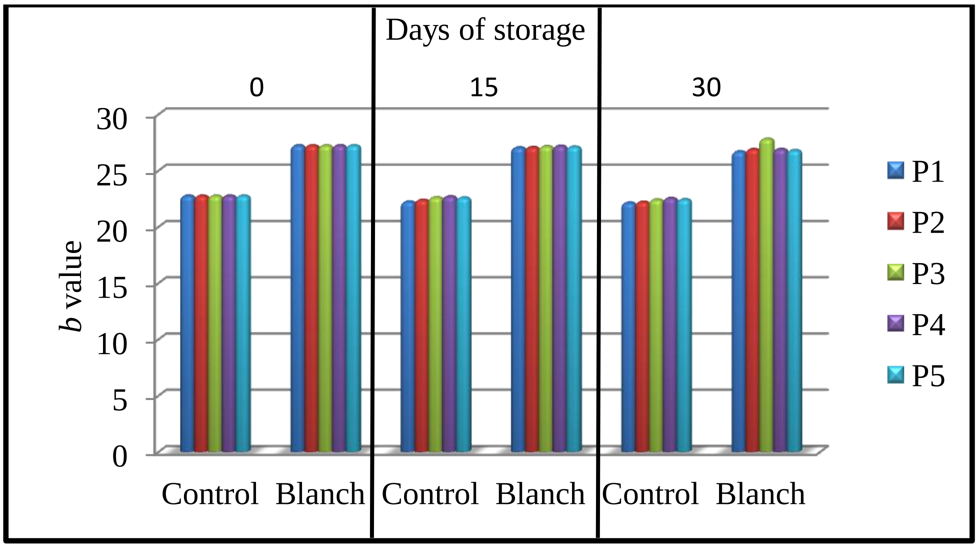

Figure 4.20 – Effect of packaging material and storage on colour *b* value

Comparing the treatments P4 showed a lower reduction in colour *b* value apart from other treatments. So, P4 was observed as the best treatment with lesser loss of colour *b* value during storage. Similar results were found in storage of PE and in storage of laminated aluminum foil with *b* value as 30.00 and 30.02 respectively by (Che Man and Sanny, 1996).

4.6.6 Effect of packaging material and storage on texture attributes

The texture parameters like firmness and toughness of dried ripened deseeded jackfruit bulbs was found to be decreasing with increase in storage period.

4.6.6.1 Effect of packaging material and storage on firmness (N)

Softening of dried jackfruit bulbs is a major factor affecting the firmness quality. The effect of firmness during storage for dried jackfruit bulbs was shown in Table 4.22 and graphically represented in Figure 4.21. During storage, firmness of dried jackfruit bulbs was strongly affected due to increases in moisture content and decrease in MAP conditions. Firmness values decreased in the range of 30.81 ± 0.00 to 30.38 ± 0.02 for control and 34.80 ± 0.00 to 34.27 ± 0.02 for blanched sample under different packaging treatments. The firmness value shows a slight decrease during the storage period. This could be due to enzymatic hydrolysis of cell wall components on storage. Soliva-Fortuny *et al.*, (2002) also reported that the restriction in firmness loss could be due to stabilized respiration. Among the five types of packaging materials P4 treatment showed varied restrictions in mean respiratory rate, by the retention of firmness compared to other packaging treatments. Also Shah and Nath (2008) reported that during the storage, firmness losses due to lesser cellular breakdown from microbial growth and biochemical activity in processed litchis. The mean values of firmness during storage are presented in Appendix VIII (h).

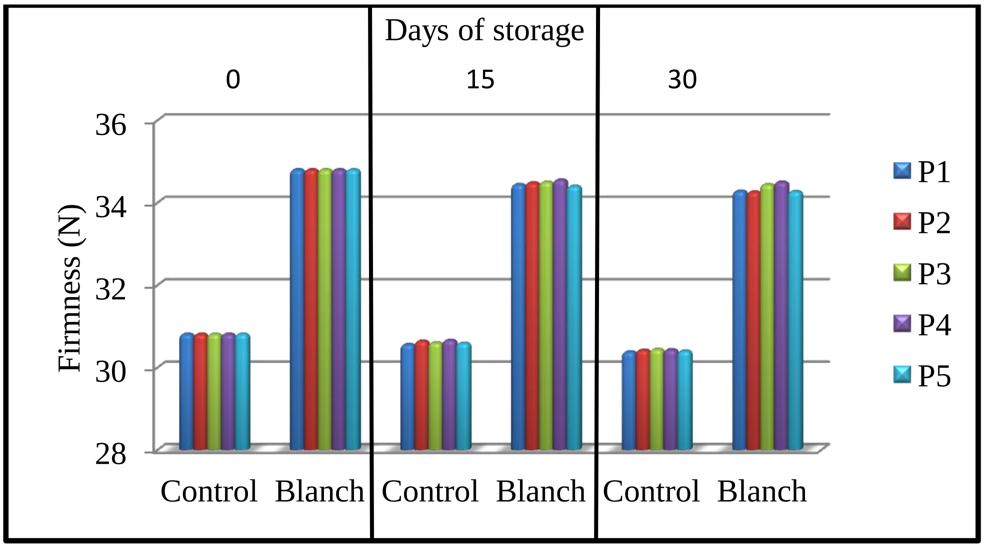

Figure 4.21 – Effect of packaging material and storage on firmness (N)

4.6.6.2 Effect of packaging material and storage on toughness (Ns)

From the Table 4.23 it is clear that toughness is decreased with increase in storage period. The minimum toughness value was found in P2 treatment followed by P1. The toughness is lost gradually during storage. The greater toughness was observed in the blanched samples compared to control may be due to lesser cellular breakdown from microbial growth and biochemical activity. The gas concentration within the package significantly affected physical quality. Since O_2 is consumed during the respiration process, its concentration decreased rapidly with increase in CO_2 concentration in the starting storage period and then reached equilibrium in all treatments. It is also observed that drying alters the texture parameters. Soliva-Fortuny *et al*., (2002) reported that tissue softening was highly influenced by both the composition of the packaging atmosphere and the permeability of the plastic bags for processed pears. The mean values of toughness during storage are presented in Appendix VIII (i).

From the statistical analysis it was observed that, in significant (p<0.05) difference was found between the packaging treatments on toughness for dried jackfruit bulb. The P4 treatment was on par with the P1, P2 and P5 treatments in case of toughness.

Comparing and observing all the quality parameters the P4 (LDPE 400 gauge) treatment was found to be the best treatment because it retains all the qualities parameters with less losses during storage period. So, in the present study toughness in P4 was found to be the best treatment.

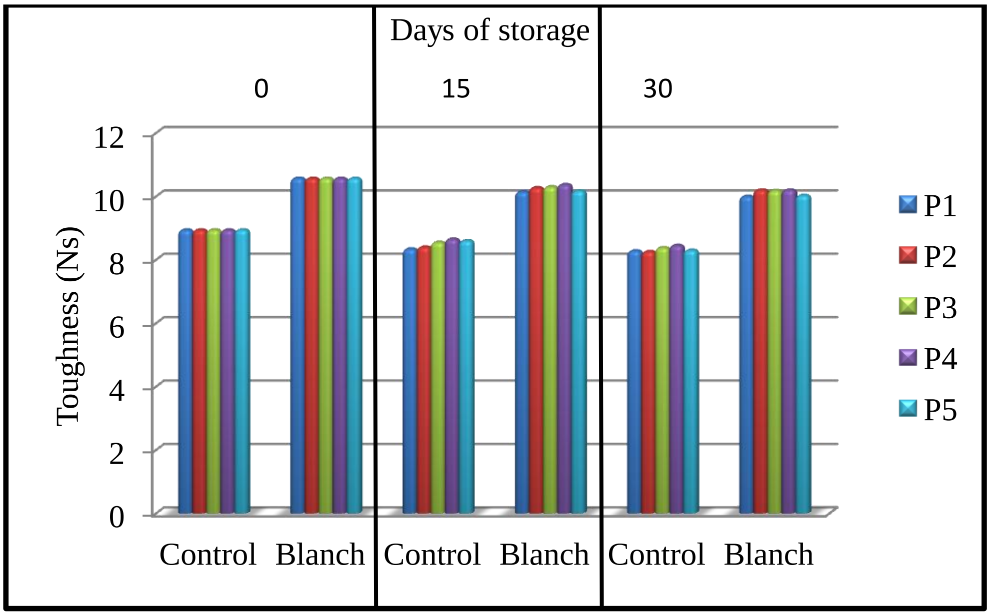

Figure 4.22 – Effect of packaging material and storage on toughness (Ns)

4.6.7 Effect of packaging material and storage on rehydration ratio

The effect of packaging materials on rehydration ratio is shown in the Table 4.24 and also represented by the Figure 4.23. From the figure it is seen that as the storage period increases rehydration ratio decreases and this trend is mainly because of the increase in moisture content during storage. Also, the tissue structure is repaired (shrink) due to attack of micro organisms during storage which decreases the rehydration ratio. The minimum rehydration ratio was observed in P2 and P5. Compare to all the treatments, P4 was found to be the best in case of rehydration ratio due to less microbial attack and also decrease rate of moisture content during the storage period. In regard to rehydration ratio an in significant differences was found between the treatments at ($p<0.05$) significant level of concordance. Similar results were reported by Kiran *et al*., (2014) for dehydrated kakrol fruit. The mean values of rehydration ratio during storage are presented in Appendix VIII (j).

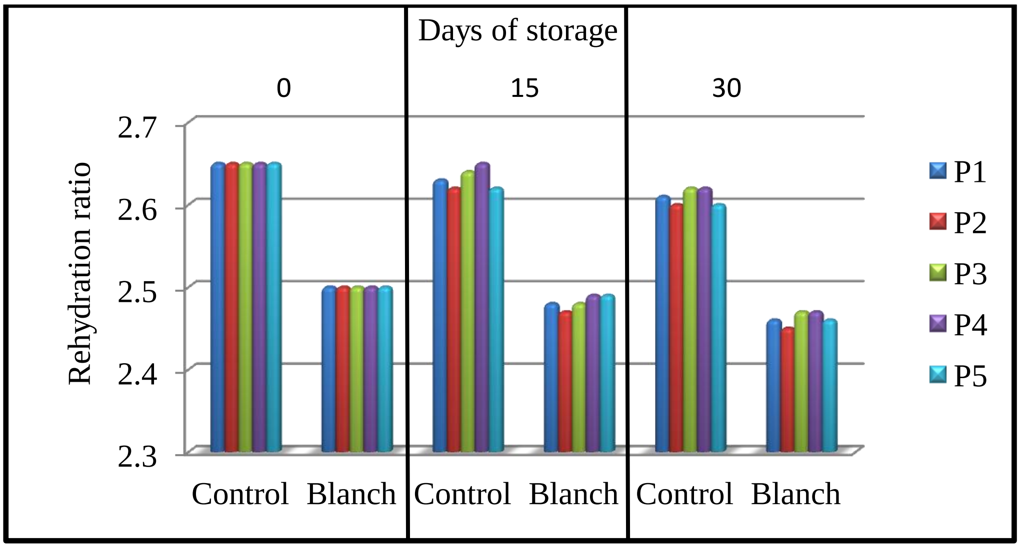

Figure 4.23 – Effect of packaging material and storage on rehydration ratio

4.7 SENSORY EVALUATION

The scores given for different treatments on different Organoleptic traits namely, colour, taste, texture and overall acceptability is presented in Table 4.25.

From the sensory scores, it was observed that dried ripened deseeded jackfruit bulb DT2 received maximum scores followed by control sample, DT3. Steam blanching for 30s followed by vacuum drying at 40°C was judged to be the best product in terms of organoleptic traits. The statistical analysis using Kendall's coefficient of concordance was applied to the all scores which showed insignificant ($p<0.05$). with colour, taste, texture and overall acceptability.

Table 4.15 – Sensory evaluation for dried ripened deseeded jackfruit bulbs

Treatment	Mean scores			
	Colour	Taste	Texture	Over Acceptability
DT1	3.37±0.01	3.59±0.02	3.12±0.10	2.99±0.39
DT2	4.22±0.02	3.79±0.02	3.58±0.01	3.84±0.02
DT3	3.43±0.01	3.21±0.01	3.61±0.02	3.23±0.01
DT4	3.38±0.01	3.02±0.01	3.34±0.01	3.51±0.02
DT5	3.35±0.02	3.00±0.03	3.33±0.01	3.50±0.01
RT1	2.94±0.01	2.86±0.01	2.91±0.01	2.56±0.01
RT2	3.35±0.01	3.43±0.05	3.41±0.01	3.62±0.01
RT3	3.38±0.01	3.57±0.11	3.39±0.02	3.55±0.02
RT4	3.54±0.02	3.36±0.01	3.51±0.01	3.47±0.01
RT5	3.52±0.01	3.32±0.02	3.50±0.01	3.45±0.01

4.9.1 Colour

Table 4.15 reveals that various treatments had a significant effect on colour on both dehydration and rehydration samples of ripened deseeded jackfruit bulb.

In the dehydration, the colour of the blanched samples received higher score compared to the other samples. Among the blanched samples, the colour of dried jackfruit bulbs with 30 s steam blanched and dried at 40°C vacuum chamber temperature sample (DT2) was found to be superior compared to DT1, DT3 and DT4 which look darker in colour.

In the rehydration, the colour of the blanched sample was superior and received the higher score compared to the other samples. Among this, the jackfruit bulb blanched for 30 s prior to vacuum drying at 40°C (RT2) was found superior compared to other treatments.

4.9.2 Taste

The perceived taste of foods is influenced by the rate at which taste compounds are released during chewing, and hence is closely associated with the texture of foods and the rate of breakdown of food structure during mastication (Clark, 1990).

From the Figure 4.24, it was found that the taste of blanched samples was accepted than those of control samples. Blanched samples vacuum dried at 40°C (DT2) received the higher score followed by the blanched sample dried at 45°C (DT1). The improvement in Organoleptic properties of the product is mainly related to the pretreatments.

Similarly for rehydration samples, it was found that the taste of blanched samples was accepted than those of control samples. Blanched rehydrated samples dried at 40°C (RT2) received the higher score followed by the rehydrated blanched sample dried at 45°C (RT1).

4.9.3 Texture

It is becoming increasingly evident that some form of texture measurement is highly desirable in the grading of all foods. The texture has been recognized as an important element in the total sensory impression obtained during the consumption of the food. Results of the table showed that the texture attributes of control samples were better than blanched samples. The control sample, DT3 received high score followed by DT2 and DT4 due to the retention of texture during the storage period.

Overall, the sample DT2 and RT2 received the high score in the sensory evaluation of vacuum dried ripened deseeded jackfruit samples.

Kendall's W test was conducted for assessing the significant ($p<0.05$) agreement among the judges with regard to colour, taste, texture etc. The results indicated that all the Kendall's wall coefficient of colour, taste, texture and overall acceptability character was significant. Hence the mean rank scores for dehydration of blanched sample (DT2, followed by DT3) could be taken to judge the superiority of one treatment over the other. Among rehydration the sample

RT2 was given higher preference. The samples selected by the panel of judges after organoleptic and statistical analyses are shown.

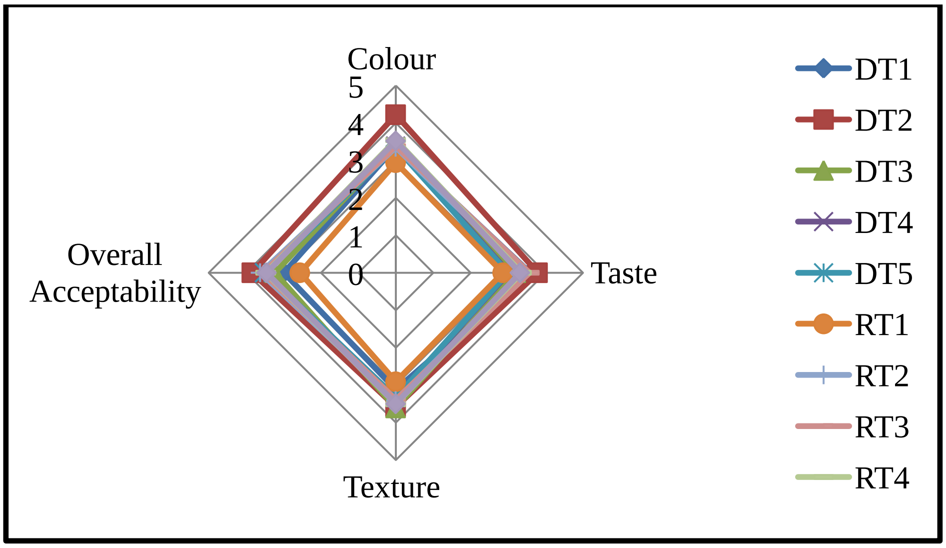

Figure 4.24 – Sensory evaluation for dried and rehydrated ripened deseeded jackfruit bulbs

The combined results of all the quality parameters, suggested that steam blanching at 100°C for 30 s followed by vacuum drying at 40°C at a constant vacuum pressure of 680 mm of Hg for 10 h drying time will reduce the moisture content from 80.62% to safe moisture content of 7.42% (d.b.). The selected dried jackfruit sample was packed in LDPE 400 gauge with MAP condition and stored at temperature can extend the shelf life up to 30 days without any quality deterioration.

4.10 COST OF VACUUM DRIED RIPENED DESEEDED JACKFRUIT BULBS

The computation for cost of dried jackfruit bulbs is given in Appendix F. The cost of production of vacuum dried ripened deseeded jackfruit bulbs per kg was found to be 240.78/-. This represents the economic viability and enhanced the potential of value addition of ripe jackfruit bulbs. The extended shelf life of ripe dried jackfruit bulbs also makes it a viable exportable commodity. The cost of analysis for dried ripened deseeded jackfruit bulbs by vacuum drying using B:C ratio is given in Appendix IX.

SUMMARY AND CONCLUSION

SUMMARY AND CONCLUSION

Fruits and vegetables are the important source of energy for human-beings and also a source of dietary fiber. India is the largest producer of fruits and vegetables after China, it processes only less than 2.5% of the production as compared to 70-83% in advanced countries. During 2012-13 India produced 81.285 million metric tonnes of fruits and 162.19 million metric tonnes of vegetables. About 35% of the total production of fruits and vegetables in India are lost due to improper processing and storage. This loss is mainly because of highly perishable nature of these commodities and also due to mechanical injury and pathological breakdown. In India, it is grown in southern and eastern states viz., Kerala, Karnataka, Tamilnadu, Goa, coastal Maharashtra and other states like, Assam, Bihar, Tripura, Uttar Pradesh and foothills of Himalayas.

In Kerala, jackfruit is an under exploited fruit cultivated as a homestead tree. Jackfruit is rich in Vitamin A, B, C and minerals such as calcium and iron. It is having immense medicinal value and is considered a rich source of carbohydrates, minerals, carboxylic acids, dietary fiber and vitamins such as ascorbic acid and thiamine. The fruits bulky nature and the availability of edible portion (around 35% of the whole fruit) make it difficult to transport and store. The fruit is seasonal and the post harvest losses are as high as 30%. Therefore, in the study conducted jackfruit is selected to develop a suitable processing to reduce losses and also to enhance the shelf life to extend the availability of this precious bulb in a ready to eat form though out the year.

Drying is the most widespread and oldest method of preservation adopted though out the world. Vacuum drying of food is relatively new. The principle of vacuum drying is that it works at low pressure and low temperatures and the air around the food is removed. This causes rapid evaporation of water inside food. Pre-treatment prevents the loss of colour by inactivating enzymes and reduce the drying time by yielding a good quality dried product.

The summary and conclusion of the study entitled “Optimisation of process parameters for vacuum drying of ripened deseeded jackfruit bulb (*Artocarpus heterophyllus L*)” is given below.

- The initial values obtained for fresh jackfruit bulbs i.e., moisture content – 82.68 ± 2.68, TSS – 22.26 ± 2.31 °Brix, pH – 5.66 ± 0.29, vitamin C – 7.76 ± 0.72, texture like firmness of 4.88 ± 4.60 (N), toughness of 1.58 ± 0.73 (Ns) and colour attributes like *L* of 61.03 ± 1.18, *a* of 8.89 ± 0.80 and *b* of 52.15 ± 0.91 respectively.
- Prior to vacuum drying the fresh jackfruit bulbs were subjected to different pre-treatments such as steam blanching and steam blanching along with citric acid at a concentration of 0.3% and 0.5% for 5 minutes. Standardization of these pretreatments were based on peroxidase and catalase test. Quality parameters were analysed based on colour and texture of the blanched samples. Both the blanching tests showed a negative result in enzymatic inactivation during the pre treatments. Considering all the above parameters steam blanching at 100°C for 30 s was standardised as the best pretreatment.
- Colour values obtained for the standardized blanched sample were *L* value of 63.24 ± 0.60, *a* value of 5.61 ± 0.42, *b* value of 58.54 ±1.99, *ΔE* value of 4.23 ± 0.04 and *Chroma* value of 51.58 ± 0.02 respectively.
- Textural parameters include firmness and toughness. Standardised steam blanched showed textural values of firmness of 7.03 ±1.47 (N) and toughness of 1.68 ± 0.45 (Ns).
- Drying studies were conducted for various vacuum chamber temperatures such as 25, 30, 35, 40 and 45°C at a fixed vacuum pressure of 680 mm of Hg.
- Different quality parameters like moisture content, TSS, pH, vitamin C, textural attributes such as firmness and toughness and colour attributes like *L*, *a* and *b* were also studied for vacuum chamber temperatures at 25, 30, 35, 40 and 45°C.

- The drying temperature i.e., vacuum chamber temperature at 40°C was standardised as the best temperature in concern of all the quality parameters.
- The moisture content values for vacuum dried ripened deseeded jackfruit bulbs was found to be 7.83 ± 0.35, 7.60 ± 0.44, 7.56 ± 0.21, 7.50 ±1.07 and 7.48 ± 0.14% (d.b.) for control samples and 7.78 ± 0.03, 7.70 ± 0.12 7.73 ± 0.70, 7.46 ± 0.27 and 7.44 ± 1.01% (d.b.) for blanched samples at 25, 30, 35, 40 and 45^{0}C for drying time of 13, 12, 11, 10 and 9 h for blanched samples and 14, 13, 12, 11 and 10 h for control samples respectively. The optimized sample was standardised at 40°C with moisture content of 7.50 ±1.07% for control and 7.46 ± 0.27% for blanched sample with drying time of 11 and 10 h.
- The TSS °Brix content obtained for vacuum dried deseeded jackfruit bulbs at 25, 30, 35, 40 and 45°C were found to be 12.88 ± 0.01, 13.78 ± 0.01, 15.50 ± 0.04, 15.93 ± 0.03 and 16.18 ± 0.01 °Brix for control samples and 10.99 ± 0.04, 11.59 ± 0.02, 12.16 ± 0.02, 13.04 ± 0.02 and 13.44 ± 0.02 °Brix for blanched samples with drying time of 13, 12, 11, 10 and 9 h for blanched sample and 14, 13, 12, 11 and 10 h for control samples respectively. The standardized sample was found at 40°C with TSS of 13.04 ± 0.02 for blanched and 15.93 ± 0.03 °Brix for control sample with drying time of 10 h and 11 h.
- The pH value of vacuum dried ripened deseeded jackfruit bulbs was obtained as 5.76 ± 0.01, 5.84 ± 0.01, 5.93 ± 0.01, 6.03 ± 0.01 and 6.12 ± 0.02 for control samples and 6.15 ± 0.02, 6.24 ± 0.02, 6.35 ± 0.02, 6.50 ± 0.11 and 6.62 ± 0.02 for blanched samples at 25, 30, 35, 40 and 45°C with drying time of 13, 12, 11, 10 and 9 h respectively. The optimized sample was obtained at 40°C with pH of 6.03 ± 0.01 for control and 6.50 ± 0.11 for blanched sample with drying time of 11 and 10 h.
- The vitamin C content for vacuum dried ripened deseeded jackfruit bulbs was found to be 6.47 ± 0.01, 6.40 ± 0.10, 6.36 ± 0.01, 6.28 ± 0.01and 5.84 ± 0.02 mg/100 g for control samples and 5.59 ± 0.02, 5.56 ± 0.02, 5.53 ±

0.03, 5.49 ± 0.02 and 5.23 ± 0.02 mg/100 g for blanched samples at 25, 30, 35, 40 and 45°C for drying time of 13, 12, 11, 10 and 9 h for blanched and 14, 13, 12, 11 and 10 h for control samples respectively. The best sample was observed at 40°C for drying time of 10 h with the vitamin C value of 6.28 ± 0.01 for control and 5.49 ± 0.02 mg/100 g for blanched sample.

- The colour attributes like *L*, *a* and *b* values obtained at 25, 30, 35, 40 and 45°C was as follows. The *L* values obtained were 28.61 ±0.10, 28.66 ± 0.10, 28.97 ± 0.01, 30.42 ± 0.01, 37.01 ± 0.02 for control sample and 42.73 ± 0.03, 42.70 ± 0.04, 42.60 ± 0.02, 42.58 ± 0.01, 42.50 ± 0.01 for blanched samples. The *a* values obtained was 10.55 ± 0.02, 12.35 ± 0.04, 12.56 ± 0.03, 13.35 ± 0.03, 18.64 ± 0.02 for control sample and 12.41 ± 0.02, 15.26 ± 0.03, 15.33 ± 0.02, 16.66 ± 0.03, 19.58 ± 0.02 for blanched samples. Similarly *b* values obtained were 18.05 ± 0.03, 19.41 ± 0.02, 20.62 ± 0.03, 22.74 ± 0.02, 24.18 ± 0.05 for control samples and 22.04 ± 0.03, 26.10 ± 0.05, 26.53 ± 0.04, 27.21 ± 0.03, 30.73 ± 0.02 for blanched samples with a drying time of 13, 12, 11, 10 and 9 h for blanched and 14, 13, 12, 11, and 10 for control samples respectively. The best samples were optimized at 40°C with the colour attributes for *L* value of 30.42 ± 0.01 for control and 42.58 ± 0.01 for blanched sample, *a* of 13.35 ± 0.03 for control and 16.66 ± 0.03 for blanched sample and *b* of 22.74 ± 0.02 for control and 27.21 ± 0.03 for blanched sample with drying time of 11 and 10 h.
- The combined effect of colour attributes like total color change (ΔE) and *Chroma* values obtained at optimized temperature 40°C were 42.68 ± 0.04 for control and 31.98 ± 0.50 for blanched samples for total color change and *Chroma* values obtained were 26.31 for control and 31.59 for blanched samples.
- The textural parameters like firmness (N) and toughness (Ns) for vacuum dried jackfruit bulbs was obtained as follows. The firmness values obtained were 21.85 ± 0.02, 28.16 ± 0.03, 29.26 ± 0.02, 30.81 ± 0.02, 32.04 ± 0.04 for control samples and 32.18 ± 0.02, 33.21 ± 0.02, 34.53 ±

0.02, 34.80 ± 0.02, 36.20 ± 0.03 (N) for blanched samples. The toughness values obtained was 4.81 ± 0.02, 6.45 ± 0.02, 8.13 ± 0.02, 8.94 ± 0.03, 9.71 ± 0.03 for control samples and 6.69 ± 0.02, 7.51 ± 0.03, 9.68 ± 0.01, 10.57 ± 0.02, 12.26 ± 0.06 (Ns) for blanched samples at 25, 30, 35, 40 and 45°C drying temperature. The optimized textural sample was selected at 40°C of firmness 30.81 ± 0.02 for control and 34.80 ± 0.02 (N) for blanched sample with toughness of 8.94 ± 0.03 for control and 10.57 ± 0.02 (Ns) for blanched sample for drying time of 11 and 9 h.

- Rehydration ratio was found to be 2.20 ± 0.10, 2.33 ± 0.10, 2.45 ± 0.10, 2.50 ± 0.15, 2.60 ± 0.10 for control and 2.50 ± 0.10, 2.56 ± 0.01, 2.60 ± 0.01, 2.65 ± 0.10, 2.70 ± 0.07 for blanched samples at vacuum chamber temperatures of 25, 30, 35, 40 and 45°C with drying time of 13. 12, 11, 10 and 9 h for blanched and 14, 13, 12, 11, 10 h for control samples respectively. The optimized sample was found at 40°C with rehydration ratio of 2.50 ± 0.15 for control and 2.65 ± 0.10 for blanched samples.
- Keeping all the above quality parameters, the best optimized vacuum chamber temperature was at 40°C for fixed vacuum chamber pressure of 680 mm of Hg with the drying time of 10 h which retains all the qualities closer to the fresh ripened deseeded jackfruit bulbs.
- Storage studies was carried out with five different packaging materials such as polythene cover, LDPE 100, LDPE 300, LDPE 400 gauges and laminated aluminum foil. The packaging material was incorporated with the MAP packaging techniques in order to increase the shelf life of the processed jackfruit bulbs.
- MAP was carried out consisted of 30% O_2 + 50% CO_2 with balance of the N_2 gas mixture was flushed to the packaging materials.
- Storage studies was carried out in an interval of 15 days including the quality analysis like moisture content, TSS, pH, vitamin C, colour attributes of *L*, *a* and *b* also includes textural parameters such as firmness and toughness. Microbial analysis was also employed to determine the microbial load present in vacuum dried deseeded jackfruit bulbs.

- Microbial count at the end of 30 days was found to be least for the sample stored in LDPE 400 gauge packages. Microbial count was found to be in range of 50 ± 1.52, 63 ± 1.52, 39 ± 2.08, 28 ± 1.00, 45 ± 2.00 $\times 10^5$ for control sample and 44 ± 2.00, 52 ± 2.00, 26 ± 2.00, 21 ± 1.52, 38 ± 1.52 $\times 10^5$ cfu/g for blanched samples with P1, P2, P3, P4 and P5 as packaging materials respectively. The microbial counts B4 treatment were within the permissible limit (not more than 50/g) prescribed by PFA, 1956. Thus LDPE 400 gauge was found to be the best packaging material with least microbial count compare to other treatments for storage of dried jackfruit bulbs.
- During the 30th day of storage studies the moisture content for vacuum dried ripened deseeded jackfruit bulbs was found to be P1 of 7.93 ± 0.01, P2 of 7.80 ± 0.02, P3 of 7.92 ± 0.01, P4 of 7.80 ± 0.02, P5 of 7.95 ± 0.01% d.b for control samples and P1 of 7.98 ± 0.01, P2 of 7.86 ± 0.02, P3 of 7.68 ± 0.01, P4 of 7.62 ± 0.01, P5 of 7.73 ± 0.02% d.b for blanched samples. The least increase in moisture content was observed in P4 packaging material which was optimized as the best treatment for storage.
- At the end of the 30th day the TSS obtained for vacuum dried deseeded jackfruit bulbs was P1 of 15.70 ± 0.02, P2 of 15.72 ± 0.02, P3 of 15.80 ± 0.03, P4 of 15.8 ± 0.02, P5 of 15.76 ± 0.02 °Brix for control samples and P1 of 12.70 ± 0.02, P2 of 12.74 ± 0.02, P3 of 12.7 ± 0.03, P4 of 12.82 ± 0.02, P5 of 12.74 ± 0.03 °Brix for blanched samples respectively. The P4 packaging material was standardized as better treatment due to lower reduction in TSS content during the storage studies.
- The pH of the vacuum dried deseeded jackfruit bulbs at the end of the 30 days was observed as 5.90 ± 0.02, 5.85 ± 0.02, 5.72 ± 0.01, 5.65 ± 0.02, 5.89 ± 0.03 for control sample and 6.02 ± 0.01, 6.20 ± 0.02, 6.10 ± 0.02, 6.24 ± 0.03, 6.10 ± 0.02 for blanched sample with P1, P2, P3, P4 and P5 packaging materials. The optimized sample was found to be P4 packaging material which showed a neutral retention in pH value.

- During storage studies the vitamin C content at the end of 30th day for vacuum dried deseeded jackfruit bulbs was found to be P1 of 6.29 ± 0.02, P2 of 6.18 ± 0.01, P3 of 6.34 ± 0.02, P4 of 6.47 ± 0.03, P5 of 6.22 ± 0.02 mg/100 g for control samples and P1 of 5.46 ± 0.03, P2 of 5.47 ± 0.01, P3 of 5.48 ± 0.03, P4 of 5.48 ± 0.03, P5 of 5.46 ± 0.01 mg/100 g for blanched samples. The best optimized sample for vitamin C was observed in P4 treatment with value of 6.47 ± 0.03 for control and 5.48 ± 0.03 mg/100 g for blanched sample.
- The colour attributes i.e., *L, a* and *b* obtained at the end of 30th day for *L* value was P1 of 24.86 ± 0.02, P2 of 23.67 ± 0.01, P3 of 24.89 ± 0.02, P4 of 25.56 ± 0.01, P5 of 24.90 ± 0.02 for control packs and P1 of 38.26 ± 0.02, P2 of 37.56 ± 0.01, P3 of 38.74 ± 0.02, P4 of 40.52 ± 0.02 and P5 of 35.46 ± 0.03 for blanched samples. Similarly for *a* value, P1 of 18.79 ± 0.02, P2 of 18.87 ± 0.02, P3 of 18.90 ± 0.02, P4 of 18.67 ± 0.02, P5 of 18.80 ± 0.02 for control samples and P1 of 21.20 ± 0.02, P2 of 20.50 ± 0.02, P3 of 20.35 ± 0.01, P4 of 20.03 ± 0.01, P5 of 21.07 ± 0.01 for blanched samples. Simultaneously for *b* value, P1 of 22.12 ± 0.02, P2 of 22.20 ± 0.02, P3 of 22.40 ± 0.02, P4 of 22.53 ± 0.01, P5 of 22.42 ± 0.01 for control samples and P1 of 26.67 ± 0.02, P2 of 26.88 ± 0.57, P3 of 27.80 ± 0.02, P4 of 26.89 ± 0.10, P5 of 26.78 ± 0.02 for blanched samples. The optimized samples was found in P4 packaging material in which the colour attributes of *L, a* and *b* value showed no significant differences within the packaging treatments.
- The textural parameters like firmness (N) and toughness (N s) at the end of 30th day for vacuum dried deseeded jackfruit bulbs was found as follows. The firmness value obtained was P1 of 30.38 ± 0.02, P2 of 30.42 ± 0.01, P3 of 30.44 ± 0.02, P4 of 30.43 ± 0.01, P5 of 30.40 ± 0.02 (N) for control samples and P1 of 34.28 ± 0.02, P2 of 34.26 ± 0.01, P3 of 34.44 ± 0.02, P4 of 34.50 ± 0.02, P5 of 34.27 ± 0.02 for blanched samples. The toughness value obtained was P1 of 8.28 ± 0.02, P2 of 8.26 ± 0.02, P3 of 8.38 ± 0.02 P4 of 8.45 ± 0.02, P5 of 8.30 ± 0.03 for control samples and P1 of 10.00 ±

0.07, P2 of 10.20 ± 0.03, P3 of 10.18 ± 0.02, P4 of 10.20 ± 0.02 and P5 of 10.03 ± 0.01 for blanched samples. The best packaging material in retaining the textural attributes was found in P4 treatment with little loss of firmness and toughness during storage studies.

- At the end of 30 days rehydration ratio was found to be P1 of 2.61 ± 0.02, P2 of 2.60 ± 0.01, P3 of 2.62 ± 0.02, P4 of 2.62 ± 0.01 and P5 of 2.60 ± 0.01 for control samples and P1 of 2.46 ± 0.01, P2 of 2.45 ± 0.01, P3 of 2.47 ± 0.02, P4 of 2.47 ± 0.01 and P5 of 2.46 ± 0.02 for blanched samples. The optimized packaging material for rehydration ratio was recorded as P4 treatment with rehydration ratio of 2.62 ± 0.01 for control sample and 2.47 ± 0.01 for blanched sample.
- Sensory evaluation was conducted based on organoleptic traits namely colour, taste, texture and overall acceptability. The sensory evaluation was conduction both for dried and rehydrated samples with control. The sensory samples include jackfruit dried at 40 and 45°C, and the best sensory score points was obtained by 40°C for both dried and rehydrated jackfruit bulbs.
- Cost of production for 1kg of dried deseeded jackfruit bulbs was Rs 240.78.

Future line of work

- Shelf-life studies of vacuum dried ripe jackfruit bulbs under refrigerated storage conditions can be carried out.
- New product development by using dried ripened jackfruit bulbs as functional ingredient and food additive.
- Osmotic dehydration of ripe jackfruit bulbs using vacuum dryer and storage studies.

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APPENDICES

APPENDIX I

The nutrient composition and nutritive values of fresh jackfruit.

Energy	37 k Cal
Moisture	83.1 g
Protein	1.6 g
Fat	0.2 g
Carbohydrate	7.3 g
Fiber	5.6 g
Ash	2.2 g
Calcium	37.0 mg
Phosphorus	26.0 mg
Iron	1.7 mg
Sodium	48 mg
Potassium	292 mg
Carotene	110 µg
Vitamin B1 (Thiamine)	0.06 mg
Vitamin B2 (Riboflavin)	0.06 mg
Niacin	0.4 mg
Vitamin C (Ascorbic acid)	7.9 mg
Mineral	0.9 g

(Source- Tee *et al*., 2007)

APPENDIX II

ANOVA table for blanching time optimization for ripened deseeded jackfruit bulb

Quality attribute	Source of variation	SS	df	MSS	F	Sig.
L (black - white	Between Groups	10.340	3	3.447	.621	0.621
	Within Groups	44.409	8	5.551		
	Total	54.749	11			
a (green to red)	Between Groups	16.445	3	5.482	21.019	0.001
	Within Groups	1.826	7	.261		
	Total	18.270	10			
b (blue - yellow	Between Groups	89.191	3	29.730	8.903	0.006
	Within Groups	26.715	8	3.339		
	Total	115.905	11			
Firmness	Between Groups	9.470	3	3.157	1.848	0.217
	Within Groups	13.666	8	1.708		
	Total	23.136	11			
Toughness	Between Groups	0.206	3	0.069	0.170	0.913
	Within Groups	3.231	8	0.404		
	Total	3.437	11			

APPENDIX III

Effect of drying on moisture content of blanched dried ripened deseeded jackfruit bulbs.

Drying time (h)	Moisture content (%) d.b				
	D1	D2	D3	D4	D5
0	82.68	82.68	82.68	82.68	82.68
1	70.54	72.45	71.34	75.46	72.56
2	65.78	67.69	70.67	68.45	65.23
3	54.68	59.9	62.34	62.14	59.67
4	43.45	47.57	58.56	56.47	50.32
5	38.7	42.56	50.86	50.45	43.45
6	30.45	36.58	40.56	39.2	34.3
7	24.34	30.34	31.56	33.24	22.13
8	19.56	24.56	22.34	25.9	12.67
9	15.46	19.78	14.35	13.37	7.38
10	12.76	13.78	10.45	7.40	
11	10.33	10.98	7.73		-
12	8.34	7.8		-	-
13	7.85		-	-	-

APPENDIX IV

Effect of drying on moisture content of control dried ripened deseeded jackfruit bulbs

Drying time (h)	Moisture content (%) d.b				
	D1	D2	D3	D4	D5
0	82.68	82.68	82.68	82.68	82.68
1	78.69	77.56	76.89	74.68	72.49
2	73.45	73.45	72.45	70.56	68.34
3	68.57	69.78	68.34	66.56	64.3
4	63.24	63.45	62.67	60.45	57.38
5	57.67	57.56	56.35	54.34	52.86
6	51.34	50.65	49.6	47.56	45.1
7	47.56	45.65	44.36	42.12	40.28
8	43.34	41.34	40.23	38.45	36.4
9	39	38.7	37.24	34.2	35.49
10	34.56	32.45	31.2	28.67	26.96
11	27.56	25.45	24.3	20.46	15.3
12	20.45	20.34	19.45	13.24	7.47
13	16.03	15.4	13.26	7.45	-
14	10.56	11.45	7.56	-	-
15	7.9	7.6	-	-	-

APPENDIX V

ANOVA table for blanched dried ripened deseeded jackfruit bulbs

Quality attributes	Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Moisture content	Between Groups	58.722	8	7.340	83.772	.000
	Within Groups	1.577	18	.088		
	Total	60.299	26			
TSS	Between Groups	42.518	8	5.315	23.107	.000
	Within Groups	4.140	18	.230		
	Total	46.659	26			
Ph	Between Groups	2.654	8	.332	5.546	.001
	Within Groups	1.077	18	.060		
	Total	3.730	26			
Vitamin C	Between Groups	19.058	8	2.382	45.314	.000
	Within Groups	.946	18	.053		
	Total	20.004	26			
L value	Between Groups	1438.625	8	179.828	15602.051	.000
	Within Groups	.207	18	.012		
	Total	1438.832	26			
a value	Between Groups	159.625	8	19.953	2508.072	.000
	Within Groups	.143	18	.008		
	Total	159.768	26			
b value	Between Groups	2168.973	8	271.122	16.496	.000
	Within Groups	295.848	18	16.436		
	Total	2464.822	26			

Firmness	Between Groups	458.864	8	57.358	218.356	.000
	Within Groups	4.728	18	.263		
	Total	463.592	26			
Toughness	Between Groups	74.836	8	9.354	211.338	.000
	Within Groups	.797	18	.044		
	Total	75.632	26			

APPENDIX VI

ANOVA table for control dried ripened deseeded jackfruit bulbs

Quality attributes	Source of variation	Sum of Squares	df	Mean Square	F	Sig.
Moisture content	Between Groups	51.260	8	6.408	76.133	.000
	Within Groups	1.515	18	.084		
	Total	52.775	26			
TSS	Between Groups	40.322	8	5.040	38.064	.000
	Within Groups	2.383	18	.132		
	Total	42.706	26			
pH	Between Groups	2.992	8	.374	10.464	.000
	Within Groups	.643	18	.036		
	Total	3.635	26			
Vitamin C	Between Groups	7.376	8	.922	12.917	.000
	Within Groups	1.285	18	.071		
	Total	8.661	26			
L value	Between Groups	789.074	8	98.634	37667.957	.000
	Within Groups	.047	18	.003		
	Total	789.121	26			
a value	Between Groups	211.312	8	26.414	21416.715	.000
	Within Groups	.022	18	.001		
	Total	211.334	26			
b value	Between Groups	1488.613	8	186.077	55761.028	.000
	Within Groups	.060	18	.003		
	Total	1488.673	26			
Firmness	Between Groups	1457.968	8	182.246	454.958	.000
	Within Groups	7.210	18	.401		
	Total	1465.178	26			
Toughness	Between Groups	210.841	8	26.355	741.778	.000
	Within Groups	.640	18	.036		
	Total	211.480	26			

APPENDIX VII

ANOVA table for microbial count on storage from 0 – 30th day for dried ripe jackfruit bulbs

Days of storage	Quality attributes	Source of variation	Sum of Squares	df	Mean Square	F	Sig.
0	Control	Between Groups	21.383	4	5.346	320.740	.000
		Within Groups	.167	10	.017		
		Total	21.549	14			
0	Blanch	Between Groups	20.756	4	5.189	268.397	.000
		Within Groups	.193	10	.019		
		Total	20.949	14			
15	Control	Between Groups	134.424	4	33.606	1738.24	.000
		Within Groups	.193	10	.019		
		Total	134.617	14			
15	Blanch	Between Groups	61.100	4	15.275	996.196	.000
		Within Groups	.153	10	.015		
		Total	61.253	14			
30	Control	Between Groups	1991.333	4	497.833	177.798	.000
		Within Groups	28.000	10	2.800		
		Total	2019.333	14			
30	Blanch	Between Groups	1890.267	4	472.567	141.770	.000
		Within Groups	33.333	10	3.333		
		Total	1923.600	14			

APPENDIX VIII

(a) – Effect of packaging material and storage on moisture content

Treatments	Moisture content (% d.b.)					
	Days of storage					
	0		15		30	
	Control	Blanch	Control	Blanch	Control	Blanch
P1	7.50±0.0^{a}	7.46±0.0^{a}	7.65±0.01^{b}	7.64±0.02^{c}	7.93±0.0^{b}	7.98±0.01^{b}
P2	7.50±0.0^{a}	7.46±0.0^{a}	7.63±0.01^{b}	7.58±0.20^{c}	7.80±0.0^{b}	7.86±0.02^{b}
P3	7.50±0.0^{a}	7.46±0.0^{a}	7.60±0.01^{b}	7.52±0.01^{b}	7.92±0.01^{b}	7.68±0.01^{a}
P4	7.50±0.0^{a}	7.46±0.0^{a}	7.56±0.02^{a}	7.50±0.01^{a}	7.80±0.02^{a}	7.62±0.01^{a}
P5	7.50±0.0^{a}	7.46±0.0^{a}	7.62±0.01^{b}	7.54±0.02^{b}	7.95±0.01^{b}	7.73±0.02^{b}

Table (b) – Effect of packaging material and storage on TSS (°Brix)

Treatments	TSS (°Brix)					
	Days of storage					
	0		15		30	
	Control	Blanch	Control	Blanch	Control	Blanch
P1	15.93±0.00	13.04±0.00	15.78±0.04^{c}	12.90±0.02^{c}	15.70±0.02^{c}	12.70±0.02^{a}
P2	15.93±0.00	13.04±0.00	15.82±0.02^{b}	12.92±0.02^{b}	15.72±0.02^{b}	12.74±0.02^{b}
P3	15.93±0.00	13.04±0.00	15.84±0.02^{b}	12.96±0.02^{b}	15.80±0.03^{a}	12.70±0.03^{b}
P4	15.93±0.00	13.04±0.00	15.90±0.02^{a}	12.98±0.02^{a}	15.82±0.02^{a}	12.82±0.02^{a}
P5	15.93±0.00	13.04±0.00	15.80±0.02^{b}	12.92±0.03^{b}	15.76±0.02^{a}	12.74±0.03^{b}

Table (c) – Effect of packaging material and storage on pH

Treatment	pH					
	Days of storage					
	0		15		30	
	Control	Blanch	Control	Blanch	Control	Blanch
P1	6.03±0.00	6.50±0.00	5.99±0.02^{a}	6.06±0.02^{d}	5.90±0.02^{a}	6.02±0.01^{c}
P2	6.03±0.00	6.50±0.00	5.95±0.01^{ab}	6.22±0.02^{b}	5.85±0.02^{b}	6.20±0.02^{a}
P3	6.03±0.00	6.50±0.00	5.92±0.01^{ab}	6.25±0.01^{b}	5.72±0.01^{c}	6.10±0.02^{b}
P4	6.03±0.00	6.50±0.00	5.87±0.02^{c}	6.34±0.02^{a}	5.65±0.02^{c}	6.24±0.03^{a}
P5	6.03±0.00	6.50±0.00	5.94±0.02^{b}	6.13±0.02^{c}	5.89±0.03^{b}	6.10±0.02^{b}

Table (d) – Effect of packaging material and storage on vitamin C (mg/100 g)

Treatments	Vitamin C (mg/100 g)					
	Days of storage					
	0		15		30	
	Control	Blanch	Control	Blanch	Control	Blanch
P1	6.28±0.00	5.59±0.00	6.22±0.02^{c}	5.50±0.02^{a}	6.18±0.02^{c}	5.46±0.03^{a}
P2	6.28±0.00	5.59±0.00	6.24±0.01^{b}	5.50±0.34^{a}	6.20±0.01^{e}	5.47±0.01^{a}
P3	6.28±0.00	5.59±0.00	6.24±0.01^{d}	5.53±0.02^{a}	6.20±0.02^{b}	5.48±0.03^{a}
P4	6.28±0.00	5.59±0.00	6.26±0.02^{a}	5.54±0.02^{a}	6.22±0.03^{a}	5.48±0.03^{a}
P5	6.28±0.00	5.59±0.00	6.23±0.01^{c}	5.54±0.03^{a}	6.19±0.02^{d}	5.46±0.01^{a}

Table (e) – Effect of packaging material and storage on colour *L* value

Treatments	*L* value					
	Days of storage					
	0		15		30	
	Control	Blanch	Control	Blanch	Control	Blanch
P1	30.42±0.00	42.58±0.00	27.34±0.02[d]	41.05±0.01[d]	24.86±0.02[b]	38.26±0.02[c]
P2	30.42±0.00	42.58±0.00	27.32±0.02[d]	41.34±0.03[c]	23.67±0.01[c]	37.56±0.01[d]
P3	30.42±0.00	42.58±0.00	28.34±0.02[c]	41.44±0.02[b]	24.89±0.02[b]	38.74±0.02[b]
P4	30.42±0.00	42.58±0.00	28.89±0.03[a]	42.32±0.02[a]	25.56±0.01[a]	40.52±0.02[a]
P5	30.42±0.00	42.58±0.00	28.44±0.02[b]	38.89±0.01[e]	24.90±0.02[b]	35.46±0.03[e]

Table (f) – Effect of packaging material and storage on colour *a* value

Treatments	*a* value					
	Days of storage					
	0		15		30	
	Control	Blanch	Control	Blanch	Control	Blanch
P1	13.35±0.00	16.66±0.00	15.90±0.01[b]	20.66±0.01[a]	18.79±0.02[b]	21.20±0.02[a]
P2	13.35±0.00	16.66±0.00	15.86±0.01[c]	20.05±0.01[c]	18.87±0.02[c]	20.50±0.02[c]
P3	13.35±0.00	16.66±0.00	15.90±0.02[b]	19.89±0.02[d]	18.90±0.02[a]	20.35±0.01[d]
P4	13.35±0.00	16.66±0.00	15.49±0.02[c]	19.70±0.01[b]	18.67±0.02[a]	20.03±0.01[c]
P5	13.35±0.00	16.66±0.00	15.98±0.01[a]	20.59±0.01[b]	18.80±0.02[b]	21.07±0.01[b]

Table (g) – Effect of packaging material and storage on colour *b* value

Treatments	*b* value					
	Days of storage					
	0		15		30	
	Control	Blanch	Control	Blanch	Control	Blanch
P1	22.74±0.00	27.21±0.00	22.22±0.02[e]	27.03±0.02[b]	22.12±0.02[d]	26.67±0.02[b]
P2	22.74±0.00	27.21±0.00	22.37±0.01[d]	27.06±0.01[b]	22.20±0.02[c]	26.88±0.57[a]
P3	22.74±0.00	27.21±0.00	22.60±0.02[b]	27.14±0.02[a]	22.40±0.02[b]	27.80±0.02[a]
P4	22.74±0.00	27.21±0.00	22.68±0.01[a]	27.17±0.01[a]	22.53±0.01[a]	26.89±0.10[b]
P5	22.74±0.00	27.21±0.00	22.57±0.01[c]	27.10±0.04[a]	22.42±0.01[b]	26.78±0.02[b]

Table (h) – Effect of packaging material and storage on Firmness (N)

Treatments	Firmness (N)					
	Days of storage					
	0		15		30	
	Control	Blanch	Control	Blanch	Control	Blanch
P1	30.81±0.00	34.80±0.00	30.56±0.01[c]	34.44±0.01[c]	30.38±0.02[b]	34.28±0.02[c]
P2	30.81±0.00	34.80±0.00	30.64±0.01[a]	34.48±0.01[c]	30.42±0.01[a]	34.26±0.01[c]
P3	30.81±0.00	34.80±0.00	30.60±0.02[b]	34.50±0.02[b]	30.44±0.02[a]	34.44±0.02[b]
P4	30.81±0.00	34.80±0.00	30.66±0.01[a]	34.55±0.01[a]	30.43±0.01[a]	34.50±0.02[a]
P5	30.81±0.00	34.80±0.00	30.59±0.01[b]	34.40±0.02[d]	30.40±0.02[a]	34.27±0.02[c]

Table (i) – Effect of packaging material and storage on toughness (N sec)

Treatments	Toughness (N sec)					
	Days of storage					
	0		15		30	
	Control	Blanch	Control	Blanch	Control	Blanch
P1	8.94±0.00	10.57±0.00	8.34±0.01[d]	10.14±0.01[c]	8.28±0.02[c]	10.00±0.07[b]
P2	8.94±0.00	10.57±0.00	8.40±0.02[c]	10.27±0.01[b]	8.26±0.02[c]	10.20±0.03[a]
P3	8.94±0.00	10.57±0.00	8.55±0.02[b]	10.30±0.02[b]	8.38±0.02[b]	10.18±0.02[a]
P4	8.94±0.00	10.57±0.00	8.65±0.02[a]	10.37±0.02[a]	8.45±0.02[a]	10.20±0.02[a]
P5	8.94±0.00	10.57±0.00	8.60±0.02[a]	10.17±0.02[c]	8.30±0.03[c]	10.03±0.01[b]

Table (j) – Effect of packaging material and storage on rehydration ratio

Treatments	Rehydration Ratio					
	Days of storage					
	0		15		30	
	Control	Blanch	Control	Blanch	Control	Blanch
P1	2.65±0.00	2.50±0.00	2.63±0.01[a]	2.48±0.02[a]	2.61±0.02[a]	2.46±0.01[a]
P2	2.65±0.00	2.50±0.00	2.62±0.02[a]	2.47±0.01[a]	2.60±0.01[a]	2.45±0.01[a]
P3	2.65±0.00	2.50±0.00	2.64±0.02[a]	2.48±0.02[a]	2.62±0.02[a]	2.47±0.02[a]
P4	2.65±0.00	2.50±0.00	2.65±0.01[a]	2.49±0.01[a]	2.62±0.01[a]	2.47±0.01[a]
P5	2.65±0.00	2.50±0.00	2.62±0.02[a]	2.49±0.01[a]	2.60±0.01[a]	2.46±0.02[a]

APPENDIX IX

Sensory Evaluation Card

Name of Examiner: Date:

Samples	Colour	Taste	Texture	Overall Acceptability
DT1				
DT2				
DT3				
DT4				
RT1				
RT2				
RT3				
RT4				

5 – Like very much
4 – Like
3 – Neither like nor dislike
2 – Dislike
1 – Dislike very much

Signature of examiner

APPENDIX X

Cost of analysis for dried ripened deseeded jackfruit bulbs by vacuum drying with B:C ratio

Cost of the vacuum dryer	=	950000/-
Cost of steam blancher	=	68681/-
Cost of weighing balance	=	29750/-
Cost of MAP	=	116500/-
Life span of the unit (n)	=	10 years
Annual usage	=	275 days
Interest rate (i)	=	4.0% per annum

I. Fixed cost per year

Fixed cost of the Equipments (E) (vacuum dryer, steam blancher, MAP and electronic balance)	=	$\frac{i(i+1)^n}{(i+1)^n - 1} \times E$
	=	$\frac{0.04(0.04+1)^{10}}{(0.04+1)^{10} - 1} \times 1164931$
	=	Rs. 698958/-
Housing, Insurance and Taxes (vacuum dryer)	=	4% of initial cost of vacuum dryer
	=	$950000 \times \frac{4}{100}$
	=	Rs. 38,000/-
Housing, Insurance and Taxes (steam blancher)	=	4% of initial cost of steam blancher
	=	$1{,}00{,}000 \times \frac{4}{100}$
	=	Rs. 4,000/-
Housing, Insurance and Taxes (MAP)	=	4% of initial cost of MAP
Total fixed cost/year	=	$1{,}00{,}000 \times \frac{4}{100}$
	=	4000/-
	=	698958+38000+4000+4000
	=	Rs. 744958/- per year

II. Variable cost per year

a) Repair and maintenance charge of equipments

i) Repair and maintenance charge of vacuum dryer	=	5% of initial cost of the vacuum dryer
	=	$950000 \times \frac{5}{100}$
	=	Rs. 47500/-
ii) Repair and maintenance charge of steam blancher	=	5% of initial cost of the steam blancher
	=	$68681 \times \frac{5}{100}$
	=	Rs. 3434/-
iii) Repair and maintenance charge of MAP	=	5% of initial cost of the MAP
	=	$116500 \times \frac{5}{100}$
	=	5825/-
Total repair and maintenance charges	=	i+ii
	=	475000+3434+47500
	=	Rs. 56759/-

b) Cost of energy

Energy requirement for vacuum	=	10 kWh/10 h
dryer	=	10x10x275
	=	27500
Energy requirement for steam blancher	=	15 kWh/8 h
Energy requirement for MAP	=	2 kWh/ h
	=	10x20x275
	=	55000/-
	=	2x0.5x275
	=	275
Total cost of energy per year	=	Rs. **580325/-**

c) Labour charges

No. of labours	=	2
Labour charge per day	=	200/-
Cost of labour per year	=	2x200x275

	=	Rs. **110000/-**

d) Cost of raw materials

Cost of jackfruit	=	100/kg
Total quantity of jackfruit required per batch	=	20 kg/batch
Cost of sweet jackfruit per year	=	100×20×275
	=	Rs. **550000**
Total variable cost/year	=	a+b+c+d
	=	56759+580325+10000+550000
	=	1198084/-
	=	329473100/- per year
Total cost of the production jackfruit	=	Total fixed cost+total variable cost
	=	744958+329473100
	=	330218058/-
Total production of jackfruit/year	=	5x275
	=	1375 kg/year
Cost of production of one kg of jackfruit	=	$\frac{\text{Total cost of operation}}{\text{Total quantity of sweet orange peel powder}}$
	=	$\frac{330218058}{1375}$
	=	**240.78/kg**
Market price of one kg of jackfruit	**=**	Rs. 300**/-**
Benefit-cost ratio	**=**	**1.02**

ABSTRACT

OPTIMISATION OF PROCESS PARAMETERS FOR VACUUM DRYING OF RIPE JACKFRUIT BULBS ((*Artocarpus heterophyllus L.*)

By

PADMAVATHI.D
(2013 - 18 - 108)

ABSTRACT OF THE THESIS

Submitted in partial fulfillment of the requirement for the award of 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

2015

ABSTRACT

Jackfruit is an underexploited fruit and commonly referred as poor man's fruit. Jackfruit is rich in Vitamin A, B, C and minerals such as calcium and iron and is also having immense medicinal value. It is a rich source of carbohydrates, minerals, carboxylic acids and dietary fiber. Based on peroxidase test, catalase test, colour and texture attributes the steam blanching for 30 s was standardised as pre-treatment. This fruit is seasonal and the post harvest losses are as high as 30%. Therefore, there is a need to develop a suitable processing protocol to reduce losses and also to enhance the shelf life and to extend the availability of this precious bulb in a ready to eat form though out the year. The deseeded jackfruit bulb after the pretreatment was dried in a vacuum dryer at a fixed vacuum chamber pressure of 680 mm of Hg. The drying was done at temperatures of 25, 30, 35, 40 and 45 $^{\circ}$C. The vacuum chamber temperature of 40 $^{\circ}$C was standardized on the basis of quality parameters like pH, TSS ($^{\circ}$Brix), vitamin C, colour, texture and rehydration ratio. The drying time required to reach a safe moisture content of 7.46 ± 0.27% (d.b) at 40 $^{\circ}$C was 10 h. Storage studies were conducted in 5 types of packaging materials such as polythene cover, LDPE 100, LDPE 300, LDPE 400 gauge and laminated aluminum foil with MAP of 30% O_2 + 50% CO_2 (with balance of N_2) gas mixtures. The quality of the stored product was assessed in terms of moisture content, pH, TSS ($^{\circ}$Brix), vitamin C, colour, texture, rehydration ratio and also by microbial analysis in every 15 days interval. Sensory analysis was also conducted as traits and was done based on Kendall's coefficient of concordance tests. At the end of 30 days LDPE 400 gauge resulted in less loss of quality parameters.

So deseeded jackfruit bulbs, steam blanched at 100 $^{\circ}$C for 30 s followed by vacuum drying at 40 $^{\circ}$C at a fixed vacuum chamber pressure of 680 mm of Hg for 10 h. The dried product packed in 400 gauge LDPE films can be stored at room temperature for 30 days without any quality deterioration.

കുരുകളഞ്ഞ പഴുത്ത ചക്കയുടെ വാക്വംഡ്രയിങ് സ്ഥിരീകരണം

'പാവപ്പെട്ടവന്റെ പഴം' എന്നറിയപ്പെടുന്ന ചക്ക,ഉത്പാദനത്തിൽ മുൻപന്തിയിലാണെങ്കിലും ഇതിന്റെ വലിയൊരു പങ്ക് ഉപയോഗ ശൂന്യമായി പോവുന്നു. ചക്ക വിറ്റാമിൻ എ, ബി, സി എന്നിവയാലും കാത്സ്യം, ഇരുമ്പ് എന്നീ ധാതുക്കളാലും സമ്പുഷ്ടമാണ്. കൂടാതെ അന്നജം ധാതുക്കൾ, കാർബോക്സിലിക്ക് ആസഡ്,നാര് എന്നിവയുടെ സാന്നിധ്യം മൂലം വളരെയേറെ ഔഷധമൂല്യങ്ങുടെ ഒരു ഉറവിടമാണ് ഈ ഫലവർഗ്ഗം. കുരു കളഞ്ഞ പഴുത്ത ചക്കയുടെ പ്രീട്രീറ്റ്മെന്റ് സമയം ക്രമപ്പെടുത്തുന്നതിനായി പെറോക്സിഡേസ് ടെസ്റ്റ്, കാറ്റലേസ് ടെസ്റ്റ്, നിറം,ഘടന എന്നിവ പരിശോധിച്ച്ഈ മാനദണ്ഡങ്ങളെല്ലാം അടിസ്ഥാനമാക്കി 30 സെക്കന്റ് സമയത്തേക്കുള്ള സ്റ്റീം ബ്ലാഞ്ചിങ് രീതി ക്രമീകരിച്ചു. ഇങ്ങനെ നിലവാരപ്പെടുത്തിയ ചക്കയുടെ ഗുണം നിർണ്ണയിക്കുന്നതിനായി വാക്വം ഡ്രയറിൽ 25°C, 30°C, 35°C, 40°C, 45°C എന്നീ താപനിലകളിൽ പഠനം നടത്തി. 40°C-ൽ 7.46$\pm$0.27% ഈർപ്പമുള്ള അവസ്ഥ ഉത്തമമാണെന്ന് ക ത്തി. ക്രമീകരിച്ച നിലയിലും ഈർപ്പത്തിലുമുള്ള ഉൽപന്നത്തിന്റെ പി.എച്ച്, TSS(°Brix), വിറ്റാമിൻ സി, നിറം, ഗുണം, റീഹൈഡ്രേഷൻ അനുപാതം എന്നിവ പരിശോധിക്കുകയും വിറ്റമിൻ സി, നിറത്തിന്റെ ഒരു സൂചകമായ 'L-മൂല്യം'എന്നിവ ഒഴികെയുള്ള എല്ലാ ഘടകങ്ങളും കൂടി വരുന്ന പ്രവണത നിരീക്ഷിക്കുകയും ചെയ്തു. തെരഞ്ഞെടുത്ത വാക്വം ഡ്രൈ ചെയ്ത സാമ്പിളിന്റെ സംഭരണശേഷി നിർണ്ണയിക്കുന്നതിനായി 30%O_2+50%CO_2+N_2 എന്നീ വാതക മിശ്രിതങ്ങളാൽ MAP ചെയ്ത ശേഷം പോളിത്തീൻ കവർ, LDPE 100, LDPE 300, LDPE 400, ലാമിനേറ്റഡ് അലുമിനിയം ഫോയിൽ എന്നിവ കൊ ് പാക്ക് ചെയ്തു. ഗുണനിലവാരം അടിസ്ഥാനമാക്കി പാക്കേജിങ് മെറ്റീരിയൽ തെരഞ്ഞെടുത്തു നടത്തിയ പഠനങ്ങളിൽ 30 ദിവസത്തോളം ചക്ക കേടുകൂടാതെ സൂക്ഷിക്കാമെന്ന് ക ത്തി. അതിനു ശേഷം സംഭരിച്ച ഉൽപന്നങ്ങളുടെ സെൻസറി ടെസ്റ്റ് നടത്തി. പരീക്ഷണ ഫലങ്ങളെ അടിസ്ഥാനമാക്കി 30സെക്കന്റ് സമയം സ്റ്റീം ബ്ലാഞ്ച് ചെയ്ത്, 40°Cൽ വാക്വം ചേമ്പറിൽ ഉണക്കി, LDPE 400 കവറിൽ പാക്ക് ചെയ്ത കുരുകളഞ്ഞ പഴുത്ത ചക്ക ഗുണമേൻമയിലും സംഭരണ ശേഷിയിലും മികച്ചതായി ക ത്തി.