DEVELOPMENT, PACKAGING AND STORAGE OF INTERMEDIATE MOISTURE JACKFRUIT (*Artocarpus heterophyllus* L.)

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Development, packaging and storage of intermediate moisture jackfruit (*Artocarpus heterophyllus* L.)"** is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other University or Society.

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INTRODUCTION

India is the second largest producer of fruits in the world after China. Crop diversification has led to rise in horticultural production, which has reached 185.2 billion tonnes in 2010 (Yadav and Singh, 2014). A wide variety of fruits are grown in India due to the diverse climatic conditions prevailing in various parts of our country. The vegetable and fruit production sector contributes more than 30 per cent of the agricultural GDP. But many of these fruits remain under exploited even now. Seasonality and high perishability of certain fruits lead to gluts in the market during peak season and farmers are forced to sell their produce at throw away price. During peak harvest season, a large quantity of these fruits is wasted due to improper handling and lack of preservation facilities (Chaudhry and Malik, 1994). Better post-harvest management practices and processing techniques can solve this problem to a great extent. Adoption of proper post-harvest management practices will help farmers to earn more from their produce and will also help to reduce the post-harvest losses.

Many of the under utilised fruits are rich in nutrients and have unique organoleptic characters, but they do not have much economic status in the market like other commercialized fruits. Lack of awareness and difficulties in consumption, transportation and storage may be the reason for their under utilisation. Jackfruit (*Artocarpus heterophyllus* L.), belonging to family Moraceae, is one among such fruits. It is indigenous to the rain forests of the Western Ghats of India. Even though it is rich in nutrients, it is less exploited. There are a number of factors that are responsible for the less commercial utilisation of this fruit. Large dimension of the fruit, large portion of inedible tissue in the form of unfertilized floral parts, the spiny outer skin, large number of seeds, sticky latex, etc. are some of those factors. In fact, edible portions amount only to 30-35 per cent of the total weight of the fruit. Transportation and packaging costs are consequently very high and it creates barriers in the sale of the unprocessed fruit outside local markets (Saxena *et al*., 2012).

The word *Artocarpus* is derived from the Greek words *artos* (bread) and *carpos* (fruit), as reported by Bailey (1949). The name "Jackfruit" is derived from the Portuguese term "jaca", which in turn, is derived from the Malayalam language term, "chakka". In India, it has wide distribution in Assam, Tripura, Bihar, Uttar Pradesh, the foothills of the Himalayas and South Indian states of Kerala, Tamil Nadu and Karnataka. Kerala is one of the leading states in jackfruit production. The area and production of jackfruit in Kerala is estimated to be 78,148 ha. and 281 million fruits, respectively. It is popularly known as poor man's fruit in the eastern and southern parts of India. The tender fruits of the tree are used as vegetable and the ripe ones as table fruits.

The fruit is a large composite with an average weight of 10 kg per unit. The yellowish bulbs constituting the perianth portion of the fruit are fleshy, fibrous and rich in sugars as well as carotenoids. The fruit is a rich source of carbohydrates, minerals, carboxylic acids, dietary fibre and also contains vitamins A, B and C (Rahman *et al*., 1999). Ripe jackfruit bulbs are consumed for their fine taste and pleasant aroma. Jackfruit is also a rich source of phenolic compounds including flavanoids. Fresh fruit is a good source of potassium, magnesium, manganese, and iron (SCUC, 2006).

Due to high perishability, jackfruit cannot be stored for a long time. During its peak season, a considerable amount of jackfruit is wasted during harvest, transportation and storage due to poor postharvest handling. Hence proper postharvest technology for prolonging shelf life and processing methods for reducing postharvest losses are necessary. Jackfruit possess excellent processing attributes with good organoleptic characters and hence is highly suitable for value addition and processing. A number of value added products have been developed from jackfruit bulb, seeds and rind. Ripe jackfruit bulbs are used to make nectar, leather, minimally processed bulb slices, canned bulbs, dehydrated products, etc. Rind of ripe fruit is made into jelly. According to Elevitch and Manner (2006), jackfruit can also be fermented and distilled to produce an alcoholic beverage. Preservation of fruits by processing has been the focus area of research in many developed and developing countries and has yielded quite a number of technologies.

The water content in food has a pivotal role in its keeping quality and may lead to microbial spoilage, enzymatic spoilage, non-enzymatic browning, etc. The basic principle of reducing water content to prolong shelf life of food has been followed from time immemorial. Drying was mainly used earlier to reduce water content. Vacuum drying, osmo-dehydration, freeze drying, etc. are some among the new techniques. Food dehydration refers to the removal of water from foods under controlled conditions that cause minimum or ideally no other changes in the food properties (Akhtar and Javed, 2013). In recent years, preservation of food by controlling water activity has gained worldwide attention.

Intermediate moisture food contains moderate levels of moisture of the order of 20-50 per cent by weight, which is less than that is normally present in fresh fruits and vegetables but more than that is left in conventionally dehydrated products.

Intermediate moisture fruits (IMFs) are semi-dried fruits and vegetables with ideal water activity (a_w) between 0.65-0.90 and at this level of a_w, the texture of the product is soft, moist and more acceptable than conventionally dried fruits. Water activity of intermediate moisture foods is reduced below that required for microbial growth, by sufficient amount of dissolved solutes. As a result, intermediate moisture foods do not require refrigeration to prevent microbial spoilage. This technique is known since long time, but it is applied only in some fruits and vegetables. Products like honey, jam, jelly, etc. are various kinds of intermediate moisture food that we have been using from time immemorial (Potter, 1986). IMFs are prepared by osmotic dehydration followed by drying. Osmotic solution contains humectants, antibrowning agent, microstatic agent and bacteriostatic agent. The first solid food consumed on the moon was an IMF. In the preparation of IM foods, some water is removed from the fresh food and the availability of the rest of water to microbial growth is reduced by the addition of suitable solutes.

Jackfruit, owing to its unique organoleptic properties, is an ideal choice for the preparation of intermediate moisture food. Since the season of availability of jackfruit is hardly three months, intermediate moisture jackfruit offers considerable potential to the food processing sector to convert it into a high value product with extended shelf life. Hence the study 'Development, packaging and storage of intermediate moisture jackfruit (*Artocarpus heterophyllus* L.)', has been laid out with the following objectives;

1. To analyse the effect of pretreatments and dehydration temperature on quality of intermediate moisture jackfruit.
2. To analyse the effect of packaging materials and storage temperature on quality of intermediate moisture jackfruit.

REVIEW OF LITERATURE

Jackfruit is a common fruit crop in Kerala. It is a good source of many nutrients and has excellent organoleptic properties. Bulky nature and latex content are the major impediments for its commercialization. In spite of the large scale production, its utilization in the form of value added products is very limited in Kerala. Conventional dehydration of jackfruit results in hard, brittle and discoloured product. Intermediate moisture foods have a texture near to fresh fruit and it can be consumed without rehydration. Hence intermediate moisture foods show great potential for utilizing surplus produce in the developing countries due to acceptable quality characteristics. By preparing intermediate moisture jackfruit, the storage life can be increased. An attempt has been made to review the literature on the research topic, "Development, packaging and storage of intermediate moisture jackfruit (*Artocarpus heterophyllus L.*)".

Jackfruit

Bailey (1949) reported that the word *Artocarpus* was derived from the Greek words *artos* (bread) and *carpos* (fruit).

Artocarpus heterophyllus Lam., belongs to the family Moraceae, along with *Ficus* spp. (fig) and *Morus* spp. (mulberry) (Chandler, 1958; Popenoe, 1974).

The name "Jackfruit" was derived from the Portuguese term "*jaca*", which was derived from the Malayalam language term, "chakka" (Anonymous, 2006; Pradeepkumar & Kumar, 2008). Manilal (2003) reported that the malayalam name "chakka" was recorded by Hendrikl van Rheede (1678-1703) in the Hortus Malabaricus, Vol. iii in Latin.

Jackfruit products

Singh and Mathur (1954) investigated on frozen jackfruit bulbs. The edible bulbs from ripe fruits (excluding the seeds) were packed with (i) dry sugar and (ii) in 50 per cent sugar syrup with 0.5 per cent citric acid, into jam cans. The product was frozen at -29° C and subsequently stored at -18°C.

Steeping of jackfruit bulbs in 0.1 per cent potassium metabisulphite solution for 30 min will improve the quality of dehydrated products (Bhatia *et al*., 1956).

Shanmugam *et al*., (1992) reported that good quality dehydrated fruit products can be obtained when sulphured at the rate of 16 lbs sulphur /ton fruit/1000 cft space and the drying ratio was 3:1.

Fresh jackfruit bulbs have good consumer preferences. Ukkuru and Pandey (2005) preserved ready to eat fresh jackfruit bulbs under vacuum (760 mm lbs pressure) by treating with 1.5 per cent KMS and 0.5 per cent sodium benzoate. Preserved bulbs showed negligible changes in the chemical constituents and were organoleptically stable for a period of 15 days under refrigerated condition.

Ripe jackfruit is used to make icecreams, drinks, jam, halwa and jelly. Desiccated pulp of jackfruit was used as dried fruit during off season. Jackfruit can also be used to prepare alcoholic liquor (Elevitch and Manner, 2006). The ripe bulbs are used to make jackfruit nectar or reduced to concentrate or powder.

Nutrient content of jackfruit

Brukil (1997) reported that jackfruit contains high levels of protein, starch, calcium and thiamine.

Jackfruit is rich in nutrients such as sodium, potassium, iron, vitamin B6, calcium, zinc and many other nutrients. It can lower blood pressure, cure fever and diarrhoea and is also known to be beneficial for fighting against asthma, ulcers, indigestion, tension, nervousness and constipation. It can slow down ageing and cell degeneration (Goswami *et al*., 2011).

Intermediate Moisture Food

The Committee for Intermediate-Moisture Foods at the National Center for Coordination of Research on Food and Nutrition (Centre National de Coordination des Etudes et Recherches sur la Nutrition et l'Alimentation) in France introduced a comprehensive definition:

Intermediate-moisture foods are food products of soft texture, subjected to one or more technological treatments, consumable without further preparation and with a shelf stability of several months assured without thermal sterilization, nor freezing or refrigeration, but by an adequate adjustment of their formulation: Composition, pH, additives and mainly water activity which must be approximately between 0.6 and 0.84 (measured at 25°C).

According to Labuza *et al.* (1970), pioneers in standardization of Intermediate Moisture Foods opined that Intermediate Moisture Foods are plastic, easily masticated and do not produce an oral sensation of dryness.

The Intermediate Moisture Food can be consumed without rehydration and is shelf stable without refrigeration and thermal processing. Hence, these foods have potential applications in military and space rations or in any other situations where refrigeration or thermal processing facilities are inadequate (Brockmann, 1970).

Jayaraman *et al.* (1975) developed intermediate moisture pineapple chunks and rings using immersion equilibration procedures. The water activity of the product was found to be 0.79. In 1976, they also reported that intermediate moisture mango slices developed from different varieties of mangoes employing the same immersion equilibration procedure using the same ingredients, had excellent flavour, colour and texture.

Intermediate moisture carrot slices were prepared by soaking the blanched slices in 6 per cent brine for 12-16h, followed by partial hot air dehydration to 50 per cent moisture level. Presence of sucrose and glycerol at 10 per cent and 5 per cent levels, respectively in the soak solution improved their texture (Jayaraman *et al.*, 1978).

Ramanuja and Jayaraman (1980) standardized intermediate moisture banana slices by soaking it in a solution containing glycerol and sugar syrup and with or without partial hot air drying. They found out that when the latter was used the banana slices had good flavour and texture and could be eaten as such. They also observed that the intermediate moisture banana slices prepared by using glycerol and sugar, yielded product much better than that prepared using sugar alone.

Sethi and Anand (1982) developed intermediate moisture carrot preserve by soaking in solution containing sugar, glycerol, water, acid and preservatives. The product got excellent sensory characters and could be consumed as such without any further rehydration.

Intermediate moisture food generally requires less drying time and lower temperatures (Levi *et al.*, 1983).

In 1985, Levi *et al.* found that intermediate moisture food with moisture content of 28 per cent or less with added preservatives are stable and are less prone to microbial spoilage.

Intermediate moisture pear product known as pear glace was developed by using corn syrup and crystalline sucrose in different proportion and found that the product prepared by using corn syrup and sucrose mixture (30 and 70 per cent) was the most desirable product in terms of colour, texture and sweetness (Barmanray, 1998).

Foods which are moist enough to be consumed without rehydration and can be preserved in a simple way at ambient temperatures come to be known as intermediate moisture foods. Fruits, vegetables, fish and meats are successfully processed into intermediate moisture range products. (Shelf stability of intermediate moisture food at ambient temperatures is mainly attributed to adjustment and control of water activity. Moisture content of intermediate moisture foods is between dried foods (less than 7 per cent moisture) and fresh foods (60-80 per cent moisture). Intermediate moisture foods have a moisture level between 10 per cent and 50 per cent and water activities vary from 0.65 to 0.90 (Prabhakar, 1999).

According to Prabhakar (1999), intermediate moisture foods can be classified as partially dehydrated foods with suitable concentrations of dissolved solids to inhibit the growth of bacteria, moulds and yeasts and to control undesirable enzymatic activity.

In intermediate moisture foods, some water is removed from the fresh food and the availability of the rest of water is reduced by the addition of suitable solutes called humectants. Humectants keep the food products moist because they allow adsorption of water and pass it on to the product, compensating for natural drying (Prabhakar, 1999).

According to Vora *et al.* (2003), intermediate moisture food contain moderate levels of moisture of the order of 20 to 50 per cent.

Intermediate moisture mango slices were prepared by soaking overnight in 68^0 Brix sugar syrup containing 20 per cent glycerol, 0.2 per cent citric acid and 0.2 per cent KMS. The soak solution was drained and the mango slices were dried at 60^0C for 2 h to get 34.8 per cent moisture (Nanjundaswamy *et al.*, 1976).

The intermediate moisture foods have an acceptable eating quality and reasonable storage stability under ambient conditions (Iman *et al.*, 2011).

Intermediate moisture foods contain moderate levels of moisture, of the order of 20-50 per cent by weight which is less than that normally present in natural fruits, vegetables or meats and more than that is left in conventionally dehydrated products. But in intermediate moisture food, the left over moisture is dissolved with sufficient amount of solutes to decrease water activity below that required to support microbial growth. As a result intermediate moisture food does not require refrigeration to prevent microbial deterioration (Akthar and Javed, 2013).

Osmotic solutions

Kaymak and Cakaloz (1996a; 1996b) evaluated that the osmotic treatment of green peas with sucrose/ trisodium citrate solution improved the drying rate and rehydration quality of final product. They concluded that trisodium citrate helped in diffusion of water. The samples treated with sucrose or trisodium citrate retained the original colour with more suitable flavour and texture when compared to non treated samples and those treated with sucrose.

Osmotic dehydration has advantages of better colour, texture and flavour retention along with minimum heat damage (Ponting *et al.* 1996).

Ideally humectants should be harmless to the consumer, should not alter the normal character of the food product and must be highly soluble in water at ambient temperatures. Humectants commonly used in food are glycerol, sugars, propylene glycol, polyethylene glycol, polyhydric alcohols such as sorbitol, and salts such as sodium chloride and potassium chloride. Permissible chemical preservatives and antimycotic agents can also be incorporated for enhancing stability of intermediate moisture foods (Prabhakar, 1999).

Panagiotou *et al.* (1999) studied the effect of solute molecular weight on mass transfer phenomena during osmotic treatment. They found out that, in osmo dehydrated fruits (apples, banana, kiwifruits), low molecular weight solutes like glucose led to higher water loss and solids uptake than higher molecular weight solutes like sucrose, under same solution concentration.

Sixty per cent sucrose treated intermediate moisture aonla segments got the highest sensory score over sucrose + glycerol (1:1) and glycerol (60^0Brix) treated intermediate moisture aonla, but retained the minimum ascorbic acid. The immersion time was 16 hours (Panwar *et al.*, 2013).

Biochemical changes

1. Moisture

The moisture content of fresh apple slices decreased from 85 to 64, 54, 52 and 49 per cent during 24, 48, 72 and 96 hours respectively during storage in crystalline sucrose (Ayub and Alam, 2002).

Pattanapa *et al.* (2010) also reported a decreasing pattern of moisture content in osmotically dehydrated mandarin.

The initial moisture content of 85.6 per cent decreased to 31.33 per cent during processing of aonla into intermediate moisture segments (Panwar *et al.*, 2013).

The moisture content of sweet and spiced intermediate moisture aonla segments ranged from 20 to 28.7 per cent and 22.0 to 31.3 per cent respectively (Panwar, 2010).

Moisture content of intermediate moisture papaya cubes varied between 25.44 per cent and 35.67 per cent (Sood, 2000).

2. Total soluble solids (TSS)

Ramanuja and Jayaraman (1980) reported 65 per cent TSS in the intermediate moisture banana prepared using sugar alone.

Sethi and Anand (1982) reported 54 per cent TSS in the intermediate moisture carrot preserve.

TSS of sweet and spiced intermediate moisture aonla segments was affected by type of cultivars, storage period and type of osmotic solution (Panwar, 2010).

3. **Acidity**

Jackfruit is known to have high titratable acidity in the top and the middle portion of the fruit. A lower titratable acidity was seen in jackfruit in the range of 0.1- 0.2 per cent. The dominant organic acids present in jackfruit were malic acid and citric acid. Succinic and oxalic acid were also identified (Selvaraj and Pal, 1989).

Sharma and Kaushal (1999), reported decrease in titratable acidity of osmotically dehydrated canned plum and was recorded in the range of 1.16 to 1.38 per cent from the initial range of 1.24 to 1.49 per cent.

The acidity value for control sample in intermediate moisture papaya was obtained as 0.297 per cent, while in samples treated with glycerol and sorbitol supplemented with sugars, low range of acidity was (0.265) obtained (Sood, 2000).

Acidity in the bulbs of jackfruit clones showed a range from 0.190 per cent to 0.595 per cent (Jagadeesh *et al.*, 2007).

The titratable acidity in intermediate moisture aonla, prepared using sucrose and glucose as osmotic agent, followed by dehydration at 50^0C, was found to be in the range of 1.08 per cent to 1.22 per cent (Panwar, 2013).

The titratable acidity of jackfruit bulbs, prepared by dipping in sugar solution followed by dehydration at 60°C, decreased as the concentration of sugar solution increased (Swami *et al.*, 2014).

4. Ash

Ash content of intermediate moisture papaya varied from 0.72 to 1.80 per cent. The control sample showed a higher value of ash content of 1.68 per cent in intermediate moisture papaya (Sood, 2000).

Ash content of dried cranberry and apricot was 0.19 ± 0.014 and 4.43 ± 0.17 per cent respectively (Cvetkovic *et al.*, 2009).

Hussain *et al.*, (2010) found that the ash content ranged from 2.62 ± 0.11 to 4.86 ± 0.13 for five varieties of dried apricot grown in Northern areas of Pakistan.

5. pH

Intermediate moisture papaya cubes prepared using honey and sugar are on acidic side as their pH ranged from 4.00 to 4.30 whereas the pH of control samples was 4.28 (Sood, 2000).

The average pH of jackfruit in nature was 5.7 and that of the osmotically dehydrated jackfruit was 5.1. The reduction observed in this study can be attributed by the incorporation of citric acid during osmotic dehydration. (Mariane *et al.*, 2011).

The pH of intermediate moisture apple slices prepared using different humectants, chemical preservatives and antioxidants, was 4.08 and it decreased to 3.90 during two months storage period (Akthar and Javed, 2013).

6. Sugar

The total and reducing sugar contents in jackfruit types studied, exhibited a range from 19.1 per cent to 32.1 per cent and 8.63 per cent to 14.6 per cent, respectively (Jagadeesh *et al.*, 2007).

The total sugars in sweet and spiced intermediate moisture aonla segments developed using the osmotic agents, sucrose and glycerol ranged from 6.2 to 28.4 per cent and 6.9 to 29.1 per cent, respectively (Panwar, 2010).

Osmo-tray dried jackfruit bulbs were developed using two different concentrations of sugar solution and found that non-reducing sugars and total sugars increased with increase on concentration of osmotic solution (Swami *et al.*, 2014).

7. Ascorbic acid

Sethi and Anand (1982) reported low content of vitamin C in aonla preserve than that in fresh fruit.

Vitamin C content in jackfruit was found to be 12 to 14 mg per 100g, which is the part of the normal protecting antioxidant (Narasimham 1990).

A study was conduted by Ayub *et al.,* (2005) to know the effectiveness of sucrose, glucose, fructose and their mixture along with chemical preservatives (potassium metabisulphite and potassium sorbate) and antioxidants (citric acid and ascorbic acid) on nutrients stability of intermediate moisture (IM) sweetened guava slices and found that ascorbic acid content decreased from 293.9 to 44.51 mg/100 g during dehydration in intermediate moisture guava slices.

The effects of drying temperatures on ascorbic acid degradation kinetics in caustic-peeled tomatoes were studied by Marfil *et al*., (2008) and found that the degradation rates were dependent on samples treatment before drying, as well as on drying temperature. Increasing drying temperature led to higher degradation rates.

The ascorbic acid content in intermediate moisture aonla segments ranged between 281 to 392 mg/100 g and the treatment containing glycerol as osmotic solution showed maximum ascorbic acid retention than that containing sucrose as osmotic solution (Panwar, 2010).

8. Total carotenoids

Carotenoids are natural pigments responsible for the yellow-reddish colour of many fruits, and vegetables. They are also related to important functions and physiological actions in human body. There is a positive correlation between ingestion of vegetables and fruits, containing carotenoids, and prevention of several chronic degenerative diseases, such as cancer, inflammation, cardiovascular disease, cataract, age, etc.

Carotenoid is known to be highly susceptible for oxidation reaction, which is accelerated at higher temperature. The total carotenoid content of fresh jackfruit reduced to 50 per cent after 5h of drying at 50^0C. However, the extent of total carotenoid degradation increased at higher drying temperatures. At 60 and 70^0C, degradation of same amount of total carotenoid content occurred within 3 and 2h respectively. The total carotenoid content after completion of drying was 0.22, 0.12 and 0.04 mg/100 g of sample, corresponding to 50, 60 and 70^{0}C (Saxena *et al.*, 2012).

9. Total flavanoids

Flavanoids are considered as the most important natural phenolics due to their broad spectrum of chemical and biological activities, including antioxidant and free radical scavenging properties (Kahkonen *et al.*, 1999). Flavanoids have been reported as antioxidants, scavengers of a wide range of reactive oxygen species and inhibitors of lipid peroxidation, and also as potential therapeutic agents against a wide variety of diseases (Ross and Kasum, 2002).

Flavanoids are polyphenolic compounds that occur naturally in plants. Flavanoids are important for human health because of their high pharmacological activities as radical scavengers (Yao *et al.*, 2004).

During storage of minimally processed jackfruit bulb, total phenolics were reported to an extent of 45 mg/100 g and flavanoids to an extent of 23 mg/100 g at the initial storage stage (Saxena *et al.*, 2009a).

The total flavanoid content of jackfruit was measured by colorimetric method and was quantified according to the standard curve prepared for rutin and the concentration of flavanoids was reported as mg of rutin equivalents per g (mg RE $g-1$) of sample. Total flavanoid content of 0.23 ± 0.016 mg RE/g was reported in fresh jackfruit bulb (Jagtap, 2010).

The total flavanoid content of the four different seed extract of *Artocarpus heterophyllus* was found to be 4.05 ± 0.01 mg/g for ethanolic fraction, 2.21 ± 0.02 mg/g for acetone fraction, 2.67 ± 0.01 mg/g for ethyl acetate fraction and 0.86 ± 0.01 mg/g for aqueous fraction of quercetin equivalent per 100 mg seed extract (Shanmugapriya *et al.*, 2011).

Drying of seaweeds led to a reduction in the total flavanoid content, although the per cent reduction declined as the drying temperature increased. A percentage reduction of 49 per cent and 30 per cent was seen at 25^0C and 40^0C, respectively (Gupta *et al*., 2011).

10. Water activity

Maillard reaction, which is one of the factors causing spoilage in food, is strongly dependent on water activity and reach a maximum rate at values of 0.6-0.7 (Loncin *et al*., 1968).

Labuza *et al*. (1970) reported that even at low water activity, sucrose hydrolyze to form reducing sugars, which may lead into browning reactions.

Ayub *et al*. (1995) found out that intermediate moisture guava slices osmotically dehydrated in 60^0 brix sucrose and sucrose:glucose (7:3) mixture was found to be more effective sweetener in lowering the water activity and retained better shelf life.

Water activity has a very important role in progressing chemical and microbiological changes within the foods. The rate of these changes can be reduced by decreasing water activity (Ayub and Shah. 2002).

Ayub and Alam (2002) reported that water activity decreased in intermediate moisture apple slices after osmotic and cabinet dehydration.

Sucrose and glucose in 7:3 ratio was found to be more effective in lowering the water activity of osmotically dehydrated persimmon slices (Ayub, 2003).

Water activity values of osmotically dehydrated papaya slices didn't show any significant differences at 7 h of osmotic process but decreased during dehydration process (Rodrigues *et al*., 2003).

In dried foods, water activity and moisture content are the most important characteristics for stability. The nature of sorption isotherms is unique for each food material. There is a relation between moisture sorption isotherms and water activity and moisture content which is used as one of the input parameters in order to improve drying process while decreasing the drying costs (Akin *et al*, 2009).

Osmotically dehydrated apples showed a decline in water activity during 0, 30, 60 and 90 minutes (Simpson *et al*. 2010).

Intermediate moisture food, such as nutritional bars, refers to food products with water activity in the range of 0.5-0.9 (Chen *et al*., 2012).

Water activity of intermediate moisture aonla ranged from 0.71 to 0.77 and that of spiced intermediate moisture aonla ranged from 0.71 to 0.75 (Panwar, 2010).

Intermediate moisture carrot pulp showed a decreasing trend in water activity with higher room temperature than at refrigeration temperature (Agarwal and Kaur, 2014).

11. Drying rate

Premi *et al*. (2010) also reported that at the end of drying of drumstick leaves, reduction in the drying rate may be due to the reduction in moisture content as drying advances.

Drying rate of jackfruit was faster at the beginning and then became slower.

Reduction in the available moisture and the development of case hardening may be the reason for the reduction in drying rate. One of the reasons for reduction in drying rate is development of shrinkage which causes reduction in porosity of the jackfruit samples with advancement of the drying process (Kaushal and Sharma, 2014).

Intermediate moisture carrot pulp showed a loss in weight with drying time. During dehydration, weight loss was rapid in the first hour of drying followed by slow decrease in weight in the subsequent hours. There was 27.7 per cent loss in weight in the 1st hour, 4.3 per cent loss in weight in the 2nd hour, 3 per cent loss in weight in the 3rd hour and only 2.3 per cent loss in weight in the 4th hour of drying (Aggarwal and Kaur., 2014).

12. Colour values (L, a, b, R, H)

Colour of jackfruit samples was affected by increase in temperature. The jackfruit samples dried at 60^0C were found better as compared to samples dried at 50 and 70^0C in terms of b value. The samples, dehydrated at 60^0C were rated better as far as drying and colour characteristics of jackfruit samples were concerned (Kaushal and Sharma, 2014).

13. Equilibrium Relative Humidity

The quality of most dried foods depends upon their physical, chemical and microbiological stability to a great extent. This stability is a consequence of the relationship between the EMC of the food material, and its corresponding water activity, at a given temperature (Myhara *et al*., 1998).

The interaction between an adsorbent and adsorbate is determined by the evaluation of heat of sorption which is enabled by the knowledge of sorption isotherms at different temperatures. Experimental sorption data have been used to evaluate the thermodynamic functions of several foods (Al-Muhtaseb *et al*., 2004).

The knowledge and understanding of moisture sorption isotherms of foods is getting more importance today. Designing, process optimization, assessment of packaging problems, shelf life and ingredient mixing predictions are done using moisture sorption isotherms (Jamali *et al*., 2006).

The critical moisture point during storage of osmo-air dehydrated apricot was at 60 per cent relative humidity with 12.5 per cent equilibrium moisture content whereas, the optimum equilibrium relative humidity was found to be 48 per cent at 25^{0}C. Dried apricot samples at and above 80 per cent relative humidity became succeptible to moulds (Sharma *et al*., 2000).

14. Non enzymatic Browning

Foods in the intermediate moisture range are more susceptible to the Maillard reaction than dry foods but less susceptible to fat oxidation (Loncin *et al*., 1968).

Studies in different dehydrated fruits revealed the various stages of non-enzymatic browning reaction and shown that the rate of reaction is strongly dependent on material composition, temperature, moisture content and pH. Maximum browning typically occur in the water activity range 0.5-0.75 (Labuza and Saltmarch., 1981).

Browning reactions increase to a maximum in the range of intermediate moisture foods and are usually slow at low humidity and at a range beyond that of intermediate moisture foods. Browning which results from the enzymatic and non-enzymatic reactions is a major concern during drying of fruits (Kiranoudis *et al*., 1992).

One of the most important chemical phenomena that may affect the food quality in processing and storage is non-enzymatic browning (Maillard reaction). For the rate of Maillard reaction, the aw of food is very critical. Between 0.6-0.7 aw, the reaction occurs with maximum rate. However, at lower and higher aw values, the reaction slows down (Demirbuker, 2003).

The non-enzymatic browning of intermediate moisture papaya cubes was found minimum (0.104) in treatment containing honey and highest (0.432) in control sample (Sood, 2000).

Development of various colour pigments including melanoidins results in Non Enzymatic Browning. The colour formation attributed to NEB process was fitted well to the kinetics of zero-order with $R^2 \geq 0.976$ (Saxena *et al*., 2012).

In jackfruit, the effect of Non Enzymatic Browning was found to be more pronounced at 70^0C, after 10 h of drying. NEB increased upto 122 per cent from initial value, whereas it was almost half from initial at 50^0C, after same duration of drying (Saxena *et al*., 2012).

Non enzymatic browning of intermediate moisture aonla segments ranged from 0.08 to 0.11 (Panwar, 2013).

15. Microbial

Coating intermediate moisture apricot with zein film inhibited microbial growth to the extent of around 2 log between control and coated batches initially and during storage period at 5 and 20°C. Addition of antioxidant and antimicrobial agents in intermediate moisture apricot also decreased the microbial count slightly compared to the plain zein film coating (Baysal *et al*., 2010).

16. Sensory evaluation

Jayaraman *et al*. (1976) reported that intermediate moisture mango slices prepared from different varieties of mango had excellent flavour, colour and texture.

Osmodehydration of jackfruit followed by drying using convective hot air at 60°C for 6 h resulted in a product with higher solids content, lower moisture content and good sensory characteristics (Mariane *et al*., 2011).

Intermediate moisture aonla segments developed using 60 per cent sucrose showed highest sensory score in colour, appearance, tatse, mouthfeel, texture and overall acceptability (Panwar, 2010).

17. Packaging

Intermediate moisture pineapple chunks and rings packed in cans and paper foil polythene laminated pouches maintained their acceptability for more than 6 months at 0^0C and upto six months at room temperature with slight browning and weakening of flavour beyond 4 months (Jayaraman *et al*., 1974).

Adsule and Anand (1977) noted that mango products showed faster rate of inversion of non reducing sugars to reducing content in plastic containers than glass containers.

Adsule and Anand (1977) reported that ascorbic acid loss of beverage was more in plastic packaging than the glass bottles.

Intermediate moisture carrot preserve remained acceptable for 6 months in glass containers with 40 per cent retention of beta carotene (Sethi and Anand, 1982).

According to Kumar and Mishra (2004), kinetics constants for quality changes were more for mango soy flour youghurt powder packaged in high density polypropylene than in aluminium laminated polyethylene pouches suggesting that ALP is better suited for packaging of MSFY powder.

Jackfruit powder packaged in Biaxially Oriented Poly Propylene pouches showed a higher kinetic constant for total colour difference than in ALP, when stored at 28^0C. ALP pouch with storage conditions of 28^0C and RH less than 75 per cent was better suited for keeping jackfruit powder (Pua *et al*., 2008).

Durrani and Verma (2011) scientifically proved that, with respect to changes in various physico-chemical constituents, microbiological, sensory quality and other organoleptic score of honey-aonla murabba, glass jar was found to be better packaging material as compared to PET jar.

Polyethylene packages maintained better colour, appearance and flavour of minimally processed jackfruit during storage (Sally *et al*., 2011).

Polypropylene packages showed minimum microbial count compared to polyethylene and polystyrene packages of minimally processed jackfruit (Sally *et al*., 2011).

3

Slight significant change was found in water activity of intermediate moisture carrot pulp packed in different packaging materials, with slightly more loss in polyethylene as compared to laminate bags (Agarwal and Kaur, 2014).

Physico-chemical changes during storage

1. Moisture

Intermediate moisture bagugosha samples showed a loss in moisture from 42.6 to 28.1 per cent during storage of 16 weeks (Rani and Bhatia, 1986).

Hussain *et al*. (2004) reported decreasing trend in moisture content of osmotically dehydrated banana slices during storage intervals. Pattanapa *et al.* (2010) also reported similar results in osmotically dehydrated mandarin.

The moisture content of corn zein edible film coated intermediate moisture apricot decreased with the storage time, for all treatments. However, moisture content of the control significantly reduced during the storage period (30% decrease at 20 °C), compared to the coated groups at 20^0 C (Baysal *et al*., 2010).

According to Panwar (2013), a significant decrease in moisture content of both sweet and spiced intermediate moisture aonla segments was observed during six months storage.

The moisture content of intermediate moisture apple slices was 4.90 per cent, which increased to 6.15 per cent during two months storage period (Akthar and Javed, 2013).

2. Total Soluble Solids

Rani and Bhattia (1986) reported that a gradual increase was seen in TSS of pear candy during storage.

TSS of jamun jelly, nectar and squash showed an increase during storage (Ashraf, 1987).

The total soluble solids in intermediate aonla segments increased significantly during six months storage and ranged between 32.0 to 48.9 per cent (Panwar, 2013).

3. Acidity

Acidity values of intermediate moisture aonla preserve gradually increased with the storage duration (Sethi, 1980).

Sethi and Anand (1982) reported a decrease in acidity of intermediate moisture carrot preserve during storage.

Akthar and Javed (2013) also observed that acidity increased during two months storage period in intermediate moisture apple slices. The acidity of intermediate moisture apple slices was 0.13 per cent which increased to 0.20 per cent during two months storage. Increase in acidity was observed to be 53.84 per cent during storage.

According to the study of Panwar (2013), titratable acidity of intermediate moisture aonla increased significantly with increase in storage period upto six months.

4. Ash content

The ash content of intermediate moisture apple slices showed an increase from 99.59 per cent to 99.76 per cent during two months storage period (Akthar and Javed, 2013).

Studies conducted by Hussain *et al*., (2014) in apricot pulp, showed an increase in ash content during storage.

An increase in ash content of chemically preserved mango pulp, stored under ambient temperature for 90 days, was reported by Akhter *et al*., (2010).

5. pH

Sethi and Anand (1982) reported that pH of intermediate moisture carrot preserve increased during storage at different temperatures.

A decrease was observed in pH of semi-concentrates prepared from orange, pineapple and tomatoes during storage when packed in aluminium foil laminates (Das and Jayaraman, 1995).

pH values of corn zein film coated intermediate moisture apricots increased at the end of storage period (Baysal *et al.*, 2010).

6. Sugar

During storage of dehydrated apple, Schrader and Thompson (1949) observed an increase in reducing sugars and a decrease in non-reducing sugars. This increase was due to inversion of non-reducing sugar to reducing sugar during storage.

Sethi (1980) reported that reducing sugars showed an increasing trend and total sugars showed a decreasing trend in intermediate moisture aonla preserved during storage.

An increase in sugar content was observed during the storage of intermediate moisture carrot preserve (Sethi and Anand, 1982).

During the storage of sand pear candy, an increasing trend was observed in the content of reducing sugars (Rani and Bhatia, 1985; 1986).

Different cultivars of aonla candy showed a decrease in reducing sugar and an increase in total sugars during 9 months storage (Nayak *et al.*, 2012).

Priya and Khatkar (2013) noticed a significant increase in reducing and total sugars in aonla preserve, prepared using sugar syrup, with increase in storage period.

A significant increase in total sugars of sweet and spiced intermediate moisture aonla segments was observed with the increase in storage period of six months. Reducing sugars of intermediate moisture aonla segments showed an increase during six month storage from 10.6 to 12.5 g/100 g (Panwar, 2013).

7. Ascorbic acid

A decrease was found in ascorbic acid content of osmotically dehydrated banana slices, prepared using sucrose and glucose mixture, during storage (Hussain *et al.*, 2004).

Singh *et al.*, (2012) prepared aonla candy using sucrose syrup and studied about disintegration trend of ascorbic acid content in it. They found out that, ascorbic acid content of aonla candy decreased with increase in storage period.

Ascorbic acid content in intermediate moisture aonla segments, prepared using sucrose and glycerol, showed a declining trend during six months storage (Panwar, 2013).

A remarkable reduction was noted in ascorbic acid (vitamin C) content of osmodehydrated jackfruit, prepared using different concentration of sugar syrup, during storage (Rahman *et al.*, 2014).

8. Carotenoids

Mehta and Tomar (1980) reported that 50 per cent of carotenoids was retained in dehydrated papaya after twelve months of storage.

A remarkable reduction was noted in β-carotene (vitamin A) content of osmodehydrated jackfruit, prepared using sugar syrup, during storage and it may be due to both oxidative and non oxidative changes (Rahman *et al.*, 2014).

9. Flavanoids

Minimally processed jackfruit bulbs stored under modified atmospheric conditions showed a decrease in flavanoid content during storage. Stabilization of the bulbs with chemical additives and the synergestic effect of modified atmospheric conditions reduced the loss in phenolics and flavanoids during storage (Sally *et al.*, 2011).

A significant increase in total flavanoids (mainly hesperidin) was found in the minimally processed citrus segments, while the juices showed a diminution in flavonoid content (Caro *et al*., 2003).

Sarkar *et al*., (2014) studied about the effect of storage and preservatives on antioxidant status of refrigerated fruit juices and found out that, flavanoid contents decrease during storage and the reduction can be minimised by the addition of sodium benzoate.

10. Water activity

Relationship between water activity and stability of food was studied by Karel (1978) and found out that each food has an optimum water activity at which it gives relatively increased storage life. Beyond that limit the rate of deterioration increases and thus reduces the storage life. Extent of the lipid oxidation, browning production, enzymatic activity and microbial growth is different at different water activity levels. Such changes are closely associated with water activity rather than moisture content of the food.

A decrease in water activity of osmotically dehydrated persimmon slices was reported by Ayub (2003).

Saxena *et al*., (2009) claimed that water activity of intermediate moisture pineapple slices reduced from 0.97-0.90 by osmotic dehydration alone. But change was found insignificant during 40 days of storage.

Panwar (2013) observed a significant decrease in water activity values of intermediate moisture aonla prepared using sucrose and glycerol, during six months storage.

11. Non enzymatic browning

A gradual increase in non-enzymatic browning of intermediate moisture aonla preserve was observed by Sethi (1980) with increasing period of storage at ambient temperature.

Jayaraman *et al.* (1999) conducted a study about browning and carotenoid oxidation in some high moisture fruit slices (50-60 per cent moisture) prepared from guava, pear, papaya and mango using hurdle technology and in semi moist slices prepared using intermediate moisture technique (30-40 per cent). He found that high moisture fruit slices were significantly less susceptible to non-enzymatic browning and carotenoid oxidation during storage than intermediate moisture fruit slices.

Non enzymatic browning showed a significant increase in intermediate moisture aonla segments with progressive increase in storage period (Panwar, 2013).

12. Microbial

Jayaraman *et al.* (1974) observed that the intermediate moisture guava prepared by immersion equilibration procedure using a soak solution containing glycerol, sucrose, water and potassium sorbate was resistant to bacterial, yeast and mould growth and was microbiologically sound for consumption upto three months at 37^0C.

Jayaraman *et al.* (1975) again revealed that total plate count in intermediate moisture pineapple chunks decreased to negligible level during storage upto 9 months.

Ramanuja and Jayaraman (1980) reported that plate count was negligible (100 colonies/gm) in intermediate moisture banana and the storage stability was up to 9 months at room temperature.

Sethi and Anand (1982) conducted studies on intermediate moisture carrot preserve and stated that microbiologically the product remained sound upto six months.

Intermediate moisture pear showed least yeast and mould count initially and upto 90 days of storage (Barmanray, 1998).

Microbial load of intermediate moisture apricots coated with corn zein edible film increased after 4 months of storage (Baysal *et al*., 2010).

No coliforms were observed with respect to EMB agar medium in all minimally processed jackfruit samples during the entire storage period (Sally *et al*., 2011).

13. Sensory

Jayaraman *et al.* (1974) found out that intermediate moisture guava samples showed slight browning and weakening of flavour beyond 4 months but it was organoleptically acceptable upto 6 months. Similar observations were made by the same group one year later in case of intermediate moisture pineapple chunks (Jayaraman *et al*., 1975).

Organoleptic quality of intermediate moisture pear showed a decrease with increase in storage period (Rani and Bhatia, 1986).

Intermediate moisture pineapple slices had good texture, colour and sensory acceptability upto 40 days of storage (Saxena *et al*., 2009).

Panwar (2013) reported that intermediate moisture aonla segments showed a significant decrease in mean score for colour, texture, taste, appearance and mouth feel of intermediate moisture aonla segments during storage and it remained acceptable upto three months with respect to colour, appearance, taste and mouth feel. During six months of storage, the overall acceptability of sweet intermediate moisture aonla segments decreased significantly from 8.0 to 4.4.

MATERIALS AND METHODS

MATERIALS

The research programme, "Development, packaging and storage of intermediate moisture jackfruit (*Artocarpus heterophyllus* L.)" was carried out using the 'Muttam Varikka' variety of jackfruit obtained from the central nursery of Kerala Agricultural University.

METHODS

The whole research programme consisted of two experiments. The first experiment was to study the "Effect of pre-treatments and dehydration temperature on quality of intermediate moisture jackfruit". The second experiment was to study the "Effect of packaging materials and storage temperature on quality of intermediate moisture jackfruit".

3.1 Effect of pretreatments and dehydration temperature on quality of intermediate moisture jackfruit

Firm, ripe bulbs of variety 'Muttam Varikka' were cleaned thoroughly in plain water after removal of seeds. They were then made into halves and subjected to additive infusion by steeping in a solution containing a binding agent (2%) in combination with a humectant (sucrose - 60%), an antioxidant (ascorbic acid - 0.2%) and a preservative (potassium metabisulphite - 0.2%), for 12 h. The binding agents used were calcium lactate, sodium alginate, corn starch and cassava starch. Jackfruit bulb halves without any pre-treatment formed the control samples. The pre-treated and control samples were dehydrated in a dryer designed and developed by the National Institute for Interdisciplinary Science and Technology, located in Thiruvananthapuram, at three different temperatures viz 40 ± 5, 50 ± 5 and 60 ± 5^0C. Thus there were five combinations of pre-treatments including the control sample and three levels of dehydration temperature. The five combinations of pre-treatments are as follows:

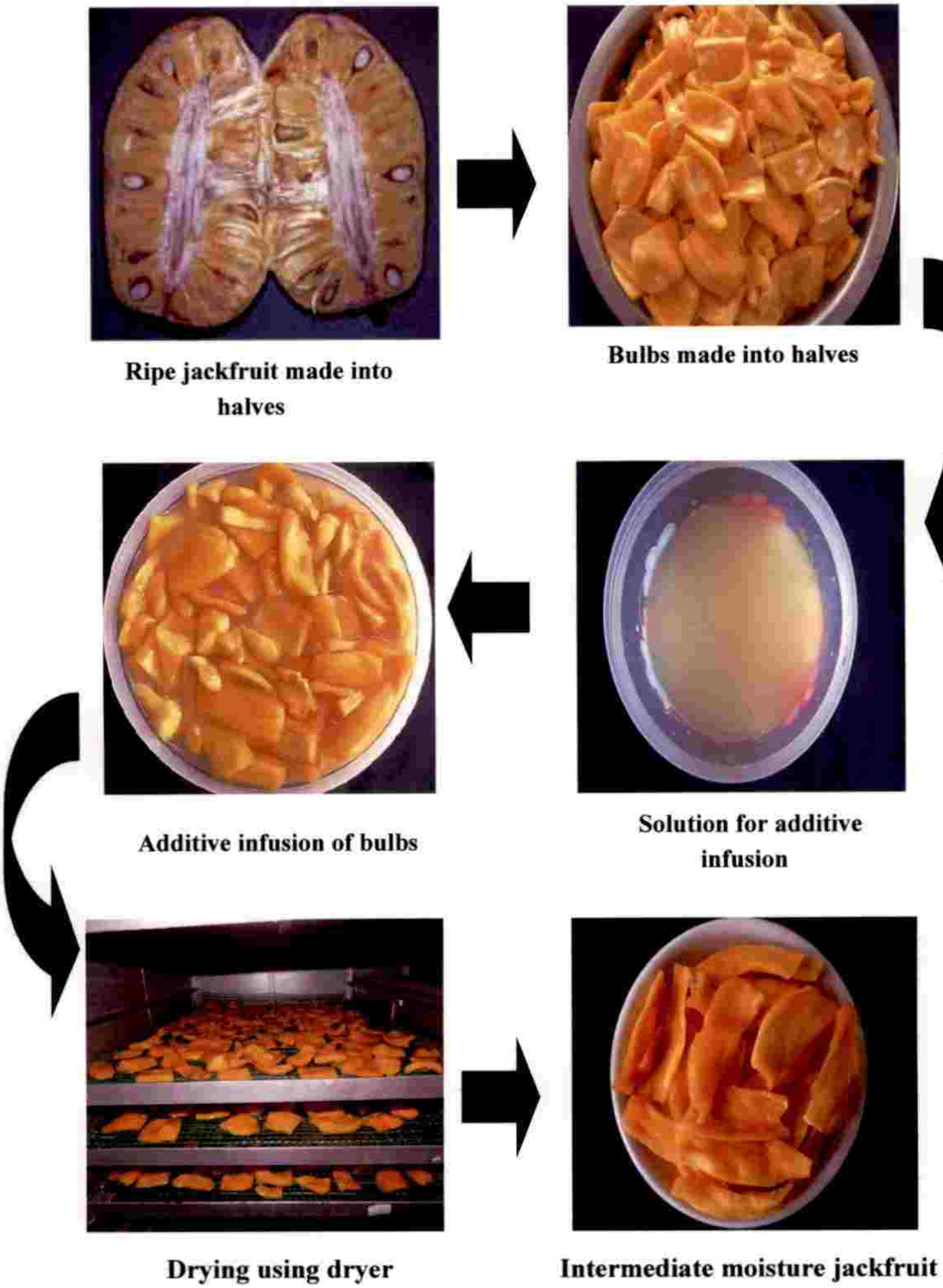

Plate 1. Flow chart for preparation of IM jackfruit

T_1: Calcium lactate (2%) + sucrose (60%) + ascorbic acid (0.2%) + potassium metabisulphite (0.2%)

T_2: Sodium alginate (2%) + sucrose (60%) + ascorbic acid (0.2%) + potassium metabisulphite (0.2%)

T_3: Corn starch (2%) + sucrose (60%) + ascorbic acid (0.2%) + potassium metabisulphite (0.2%)

T_4: Cassava starch (2%) + sucrose (60%) + ascorbic acid (0.2%) + potassium metabisulphite (0.2%)

T_5: Control (without pretreatments)

3.1.1 Lay out

The experiment was laid out in a Completely Randomized Design (CRD) with three replications each.

3.1.2 Observations

Observations on physical, biochemical and microbial characteristics of the product were taken as detailed below.

3.1.2.1 Physical characteristics

3.1.2.1.1 Moisture content

Moisture content was estimated by placing a known weight of sample in a hot air oven and drying at 50-60^{0}C to a constant weight and expressed as per cent moisture content (Ranganna, 1997).

$$\text{Moisture (\%)} = \frac{\text{Fresh weight-dry weight}}{\text{Fresh weight}} \times 100$$

3.1.2.1.2 Water activity

The water activity was recorded using water activity meter (Aqua Lab, Decagon Devices, and USA). The instrument was calibrated using saturated salt solutions of pre-standardised water activity. The samples were chopped into uniform size and filled into the sampling cups to about half the capacity and the readings were obtained directly from the equipment.

3.1.2.1.3 Drying rate

Drying rate was obtained by noting the change in weight of the product at two hours interval and expressed as the rate of residual water to dry matter (kg of water per kg of dry matter).

3.1.2.1.4 Colour values

Colour of the samples was visually identified with the help of Universal Colour Language (UCL). The Universal Colour Language was defined by the Inter-society Colour Council, National Bureau of Standards in 1946.

3.1.2.2 Biochemical parameters

3.1.2.2.1 Total Soluble Solids (TSS)

The total soluble solids (TSS) were determined with the help of digital refractometer after grinding the samples thoroughly. The readings were corrected for temperature variations and the results were expressed as degree Brix (^{0}Brix) at 20^{0}C (Ranganna, 1997).

3.1.2.2.2 Titratable acidity

The titratable acidity was estimated by titrating with 0.1N sodium hydroxide (NaOH) solution using phenolphthalein as an indicator and expressed as per cent of citric acid. A known weight of sample was ground using distilled water and made upto 100 ml in a standard flask. An aliquot of 10 ml from this was titrated against 0.1N NaOH (AOAC, 1998).

$$\text{Acidity (\%)} = \frac{\text{Normality x titre value x equivalent weight x volume made up x 100}}{\text{Weight of sample x aliquot of sample x 1000}}$$

3.1.2.2.3 Ash content

A known weight of sample, after estimation of moisture content, was initially burnt on a hot plate, followed by placing in a muffle-furnace at a temperature of 800^0C. The residue of sample left in the crucible was weighed and the total ash content was calculated as per the following formula (AOAC, 1998).

$$\text{Per cent ash content} = \frac{\text{Weight after ashing x 100}}{\text{Weight of the sample (g)}}$$

$$= \frac{W_2\text{-}W}{W_1 - W} \text{ x } 100$$

Weight of empty crucible: W (g)

Weight of empty crucible + sample before ashing: W_1 (g)

Weight of empty crucible + sample after ashing: W_2 (g)

3.1.2.2.4 pH

The pH was determined by using a pH meter after standardization with buffers (pH 4.0, pH 9.0 at 20^0C) (AOAC, 1998).

3.1.2.2.5 Reducing sugars

A known weight of sample was ground in a pestle and mortar and transferred to a 250 ml volumetric flask. About 100ml of distilled water was added followed by 2ml pre-standardised 45 per cent neutral lead acetate for clarification. Excess lead acetate was neutralized by the addition of 2ml pre-standardised 22 per cent potassium oxalate solution. The clarified solution was made upto the mark with distilled water. This was filtered through Whatman No.1 filter paper. The reducing sugars were determined by titrating the clarified filtrate against standard Fehling's solution using methylene blue as an indicator (Ranganna, 1997). The reducing sugars were calculated by the formula as given below.

$$\text{Reducing sugars (\%)} \quad \frac{\text{Fehling's factor x dilution}}{\text{Titre value x weight of sample}} \times 100$$

3.1.2.2.6 Total sugars

Filtrate (50ml) used in the estimation of reducing sugars was taken in a 100ml volumetric flask and 5 ml of concentrated HCl was added for hydrolyzing the sample. Then the hydrolysed solution was neutralized with 20 per cent NaOH by using one or two drops of phenolphthalein. Diluted HCl was added till it became colourless. Finally, the volume was made upto 100 ml and it was titrated against standard Fehlings solution using methylene blue as an indicator (Ranganna, 1997). The total sugars were calculated as given below.

$$\text{Total sugars (\%)} = \frac{\text{Fehling's factor x 250 x dilution}}{\text{Titre value x 50 x weight of sample}} \times 100$$

3.1.2.2.7 Non reducing sugars

The non-reducing sugars in the samples were determined by deducting reducing sugar content from total sugar content (Ranganna, 1997).

Non reducing sugars (%) = Total sugars (%) - reducing sugars (%)

3.1.2.2.8 Ascorbic acid

Ascorbic acid was estimated by titrating a known weight of sample with 2, 6-dichlorophenol indophenol dye, using metaphosphoric acid as stabilizing agent (AOAC, 1998).

A known weight of sample was ground using 3 per cent metaphosphoric acid and the volume was made upto 100 ml. After filtration, 10 ml of aliquot was titrated against 2, 6-dichlorophenol indophenol dye. The dye factor was calculated by titrating standard ascorbic acid solution against dye and ascorbic acid content of sample was expressed as

$$\text{Ascorbic acid (mg/100 g)} = \frac{\text{Titre value x dye factor x volume made up}}{\text{Weight of sample x aliquot of sample}} \times 100$$

3.1.2.2.9 Total carotenoids

A known weight of sample was ground in a pestle and mortar with acetone. The extract was poured into a conical flask. Extraction was continued till the residue became colourless. The extract was transferred to a separating funnel and then 10-15 ml of petroleum ether, little amount of distilled water and a little amount of anhydrous sodium sulphate was added. Then it was shaken well. The upper layer was collected and the lower layer was re-extracted. Extraction of acetone phase was repeated with small volume of petroleum ether till it became colourless. The extract was collected into a volumetric flask by passing through cotton containing small amount of anhydrous sodium sulphate and then the volume was made up with petroleum ether. The colour was measured at 452 nm using petroleum ether as blank in spectrophotometer. Results were expressed as µg/100 g of material (Ranganna, 1997).

$$\text{Total carotenoids (µg/100 g)} = \frac{\text{3.857 x optical density x volume made up x 100}}{\text{Weight of the sample}}$$

3.1.2.2.10 Total flavanoids

Aluminium chloride method was used for determination of flavanoids in the sample (Chang *et al.*, 2002). A known weight of sample (10 g) was ground using ethanol in a pestle and mortar. Then it was centrifuged to obtain clear liquid. Centrifugation was done until it became colourless. Ethanol extract of the sample were mixed with 1.5 ml of methanol, 0.1 ml of 10 per cent aluminium chloride, 0.1 ml of 1M potassium acetate and 2.8 ml of distilled water. It was kept at room temperature for 30 minutes. The absorbance of the reaction mixture was measured at 415 nm with a UV-Vis spectrophotometer (Shimadzu UV-Vis

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spectrophotometer, 1800). The calibration curve was plotted by preparing quercetin solutions of different concentrations from 12.5 to 100 g in methanol.

3.1.2.3 Microbiological analysis

The microbial analysis was conducted to detect the presence of the following organisms and their load in the product.

1. Fungi
2. Bacteria
3. *E.coli*

The microbial load in the sample was analsyed using serial dilution plate count method as described by Agarwal and Hasija (1986). Ten gram sample was added to 90 ml distilled water and shaken well to form a suspension. This gave a dilution of 10^{-2}. From this suspension, 1 ml was transferred to a test tube containing 9 ml distilled water, which gave a dilution of 10^{-3}. Similarly, 10^{-4}, 10^{-5} and 10^{-6} dilutions were prepared from these serial dilutions.

Samples of intermediate moisture jackfruit were subjected to microbiological analysis initially and also at bimonthly intervals during their storage. The samples were analysed for the population of bacteria, fungi and *E. coli* in standard plate count nutrient agar, Martin Rose Bengal agar media and EMB agar media, respectively and the results were expressed in cfu/g of sample.

3.1.2.3.1 Estimation of bacterial population

Bacterial population was estimated using 10^{-2} dilution on nutrient agar medium. One ml of 10^{-2} dilution was pipetted into a sterile petridish using a micropipette. About 20 ml of the melted and cooled Nutrient Agar media was poured into the petridish and it was swirled. After solidification, it was kept for incubation at room temperature. Three petridishes were kept as replicates for each sample. The petriplates were incubated at room temperature for 48 h. The bacterial colonies developed were counted and expressed as cfu/g of sample.

3.1.2.3.2 Estimation of fungal population

One ml of 10^{-3} dilution was pipetted into a sterile petridish using a micropipette. About 20 ml of the melted and cooled Martin Rose Bengal Agar (MRBA) media was poured into the petridish and it was swirled. After solidification, it was kept for incubation at room temperature. Three petridishes were kept as replicates for each sample. The petriplates were incubated at room temperature for 4 to 5 days. The fungal colonies developed at the end of five days were counted and expressed as cfu/g of the sample.

3.1.2.3.3 Estimation of *E.coli* population

One ml of 10^{-3} dilution was pipetted into a sterile petridish using a micropipette. About 20 ml of the melted and cooled Eosin methylene blue (EMB agar) media was poured into the petridish and it was swirled. After solidification, it was kept for incubation at room temperature. Three petridishes were kept as replicates for each sample. The petriplates were incubated at room temperature for 4 to 5 days. Appearance of metallic green sheen indicates the presence of *E.coli*.

3.1.2.4 Organoleptic evaluation

A panel of judges of different age groups judged the products for appearance, colour, flavour, texture, odour, taste, after taste and overall acceptability, based on a 9 point hedonic scale rating, soon after preparation and at bimonthly intervals during storage (Amerine *et al.*, 1965). A score of 5.5 and above was considered acceptable.

The best treatment among the five treatment combinations was selected based on organoleptic acceptability, microbial safety and biochemical composition. Thus the intermediate moisture jackfruit selected as the best one formed the sample for subsequent storage study involving various types of packaging materials.

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3.2 Effect of packaging materials and storage temperature on quality of intermediate moisture jackfruit

About 250 g of intermediate moisture jackfruit, selected as the best treatment was packed in different packaging materials and was kept under ambient and low temperature (5-7^{0}C) storage conditions to evaluate changes in the product during storage.

The packaging materials used for storage of IM jackfruit are the following.

T_1: Low density polyethylene pouches (LDPE 100 gauge)

T_2: Low density polyethylene pouches (LDPE 200 gauge)

T_3: Plastic trays over wrapped with cling film

T_4: High impact polystyrene boxes (HIPS)

T_5: Laminated aluminium foil pouches

T_6: Rigid plastic boxes

T_7: Glass jar

Storage temperature:

1. Ambient 2. Low temperature (5-7 ^{0}C)

3.2.1 Physical charactersitics

3.2.1.1 Moisture

Moisture content was estimated as in 3.1.2.1.1

3.2.1.2 Water activity

Water activity was estimated as in 3.1.2.2.2

3.2.1.3 Colour values

Colour values were estimated as in 3.1.2.2.3

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3.2.1.4 Equilibrium relative humidity

Winks Weight Equilibrium method was used to find out equilibrium relative humidity. Five gram of sample was placed in dessicators having different relative humidity. Saturated solutions of various salts were used to create different levels of relative humidity in dessicators. The gain or loss in weight of the product under different humidity was determined at an interval of one day. Changes in physical appearance and also presence of mould growth were observed. Equilibrium moisture content was found out using the following formula and was ploted against relative humidity to get pattern of equilibrium relative humidity (Ranganna, 1997).

$$\text{Equilibrium relative humidity} = \frac{\left(\begin{array}{c}\text{Weight after equilibration-} \\ \text{(Weight of sample- moisture)}\end{array}\right)}{\text{Weight after equilibration}} \times 100$$

3.2.1.5 Critical moisture point

Critical moisture point is the stage at which the product just becomes lumpy. It was obtained from equilibrium moisture humidity analysis (Ranganna, 1997).

3.2.2 Biochemical parameters

3.2.2.1 TSS

TSS content was estimated as in 3.1.2.2.1

3.2.2.2 Acidity

Acidity content was estimated as in 3.1.2.2.2

3.2.2.3 Ash

Ash content was estimated as in 3.1.2.2.3

3.2.2.4 pH

pH content was estimated as in 3.1.2.2.4

3.2.2.5 Reducing Sugars

Reducing sugars were estimated as in 3.1.2.2.5

3.2.2.6 Non-reducing sugars

Non-reducing sugars were estimated as in 3.1.2.2.6

3.2.2.7 Total sugars

Total sugars were estimated as in 3.1.2.2.7

3.2.2.8 Vitamin C

Vitamin C content was estimated as in 3.1.2.2.8

3.2.2.9 Total carotenoids

Total carotenoids were estimated as in 3.1.2.2.9

3.2.2.10 Total flavanoids

Total flavanoids were estimated as in 3.1.2.2.10

3.2.2.11 Non- enzymatic browning

The non-enzymatic browning was estimated by the method described by Ranganna (1997). The increase in absorbance of sample extract at 440 nm was taken as a measure of non-enzymatic browning.

Sample (4-5g) was extracted with 100 ml of 60 per cent ethanol. Then it was kept overnight and filtered using Whatmann No.1 filter paper to get clear extract. Then the colour was measured at 440nm in a spectrophotometer using 60 per cent alcohol as blank. The results were reported as absorbance (optical density) value.

3.2.2.12 Shelf life

Non enzymatic browning and microbial load were taken as the indicators to determine the quality and shelf life of the product.

3.2.3 Microbial observations

Microbial observations were done as in 3.1.3

3.2.4 Organoleptic evaluation

Organoleptic evaluation was done as in 3.1.4

Biochemical, microbial and organoleptic observations were taken at bimonthly interval.

3.2.5 Statistical analysis

The data obtained were analysed statistically using two way analysis of variance (ANOVA) technique. The critical difference value at five per cent level was used for making comparison among different treatments. The scores of sensory evaluation were analysed by Kendall's coefficient of concordance.

RESULTS

The results obtained in the present investigation entitled "Development, packaging and storage of intermediate moisture jackfruit (*Artocarpus heterophyllus* L.)" are presented below.

4.1 Effect of pretreatments and dehydration temperature on quality of intermediate moisture jackfruit

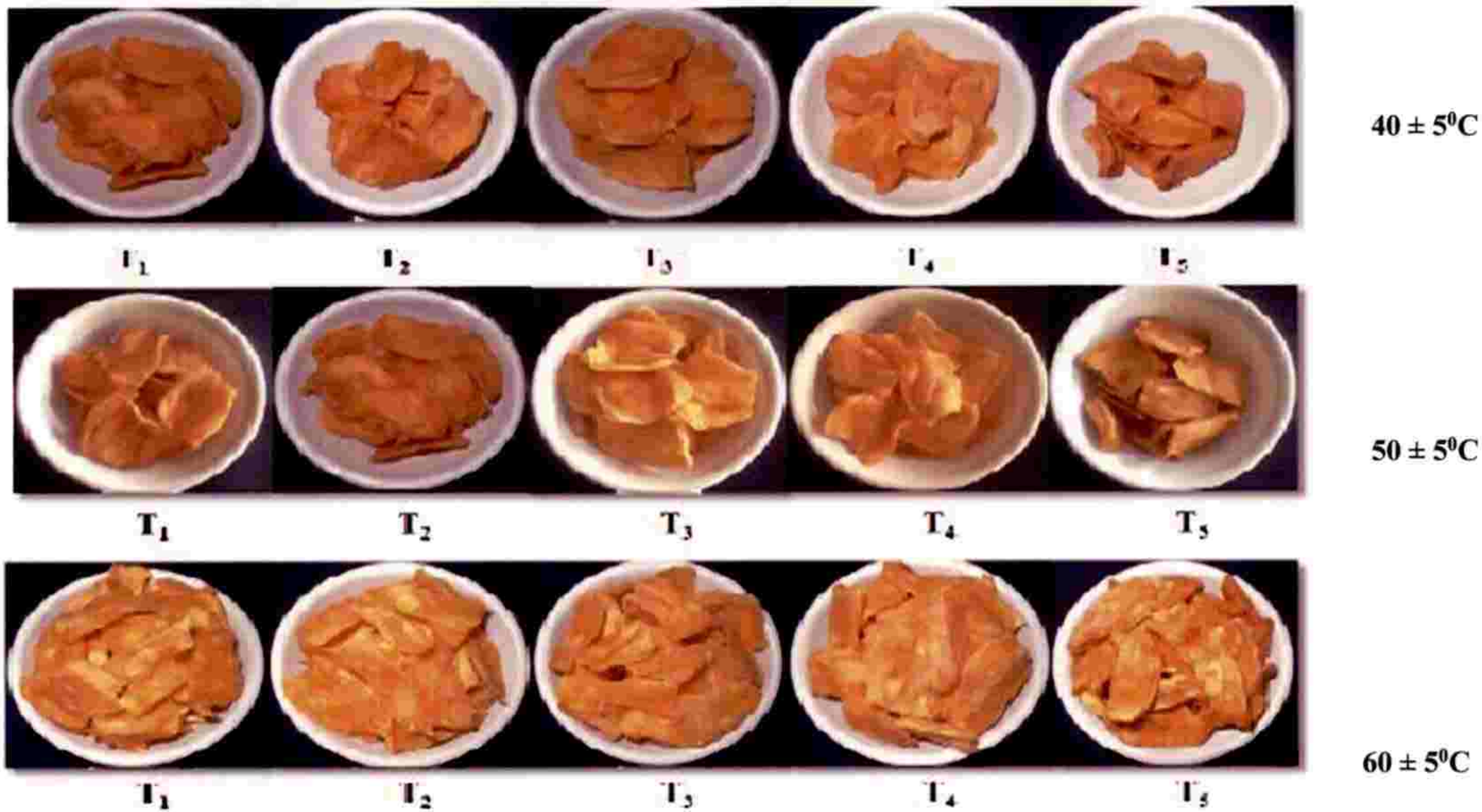
4.1.1 Physical characteristics

4.1.1.1 Moisture (%)

Moisture content of the intermediate moisture jackfruit was recorded immediately after preparation of the product. It showed a declining trend in all the treatments with increase in dehydration temperature and was in the range of 16.20 to 22.54 per cent (Table 1). Maximum moisture content (22.54) was seen in intermediate moisture jackfruit prepared using cassava starch as the matrix binding agent at a dehydration temperature of 40 ± 5^0C and the minimum (16.20) in which corn starch was used. However, significant difference in moisture content was not observed among the treatment combinations.

4.1.1.2 Water activity

A declining trend in water activity of intermediate moisture jackfruit was observed with increase in dehydration temperature in all the treatments (Table 1). Jackfruit bulbs without any pretreatments (control) showed higher water activity at all dehydration temperatures. Control samples dehydrated at 40 ± 5^0C showed the highest water activity (0.80) whereas the lowest (0.76) was seen in intermediate moisture jackfruit dehydrated at 60 ± 5^0C. Water activity of intermediate moisture jackfruit did not vary significantly among the treatment combinations.



T_1: Calcium lactate + sucrose + ascorbic acid + KMS
T_2: Sodium alginate + sucrose + ascorbic acid +KMS
T_3: Corn starch + sucrose + ascorbic acid + KMS
T_4: Cassava starch + sucrose + ascorbic acid + KMS
T_5: Control

Plate 2. Quality of intermediate moisture jackfruit dehydrated at 40 ± 5^{0}C, 50 ± 5^{0}C and 60 ± 5^{0}C

Table 1. Effect of pretreatments and dehydration temperature on moisture content and water activity of intermediate moisture jackfruit

Treatments	Moisture (%)			Water activity		
	D1 (40±5^{0}C)	D2 (50±5^{0}C)	D3 (60±5^{0}C)	D1 (40±5^{0}C)	D2 (50±5^{0}C)	D3 (60±5^{0}C)
T_1 (Calcium lactate + sucrose + AA + KMS)	21.11	20.23	20.07	0.78 (1.33)	0.77 (1.33)	0.76 (1.33)
T_2 (Sodium alginate + sucrose + AA + KMS)	22.07	20.00	19.60	0.78 (1.34)	0.77 (1.33)	0.76 (1.33)
T_3 (Corn starch + sucrose + AA + KMS)	20.62	19.00	16.21	0.78 (1.34)	0.78 (1.33)	0.76 (1.33)
T_4 (Cassava starch + sucrose + AA + KMS)	22.54	19.17	17.78	0.78 (1.34)	0.78 (1.33)	0.75 (1.33)
T_5 Control	22.50	20.31	18.58	0.79 (1.34)	0.79 (1.34)	0.79 (1.34)
CD (T)	NS			0.005 (0.002)		
CD (D)	1.42			0.004 (0.002)		
CD (TXD)	NS			NS		

AA: ascorbic acid; KMS: Potassium metabisulphite

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4.1.1.3 Drying rate

Rate of drying was faster with increase in dehydration temperature in all the treatment combinations. Loss of moisture was faster during the initial four hours and after that it showed a gradual decline. Dehydration at 60 ± 5^0C showed a steady decline throughout the process whereas at 40 ± 5^0C and 50 ± 5^0C, a steep decline was observed during the initial four hours, followed by a gradual decline afterwards. Dehydration at 40 ± 5^0C took 12 hours to reach the appropriate moisture content whereas it took 10 hours to dehydrate the product at 50 ± 5^0C and 60 ± 5^0C.

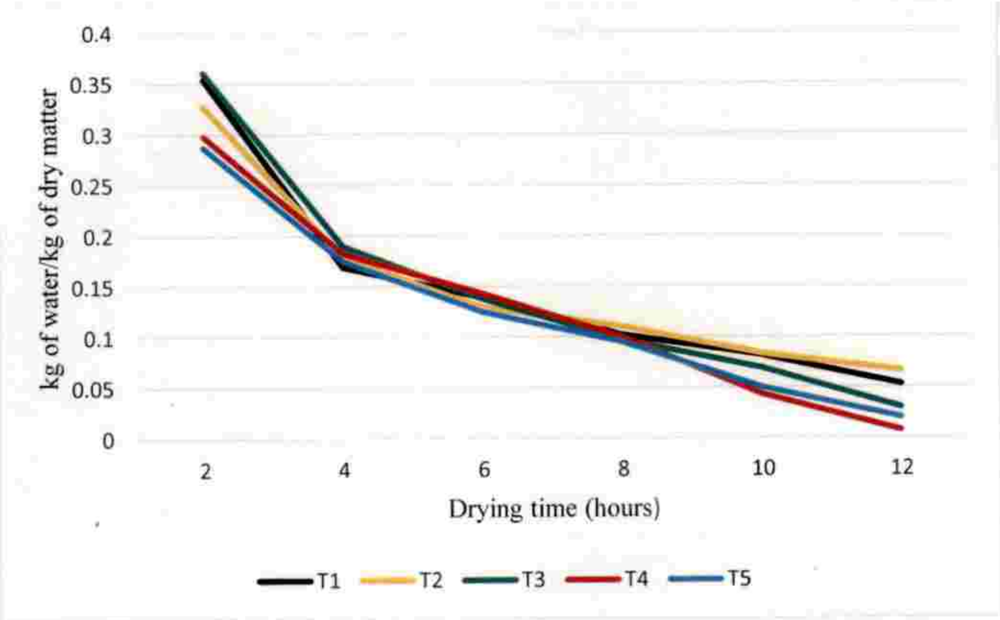


Fig 1. Drying rate of intermediate moisture jackfruit dehydrated at 40 ± 5^0C

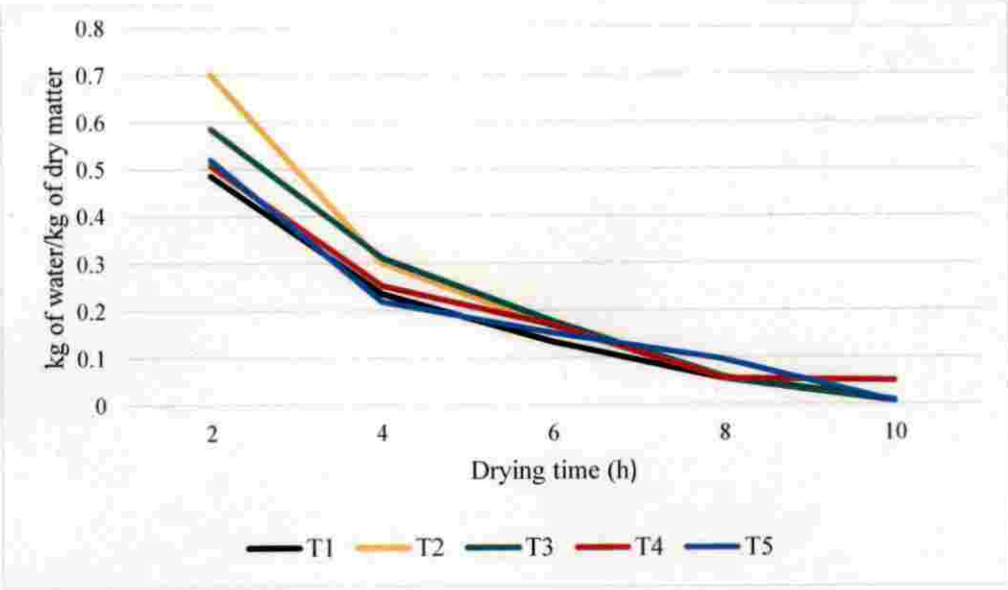


Fig 2. Drying rate of intermediate moisture jackfruit dehydrated at 50 ± 5^0C

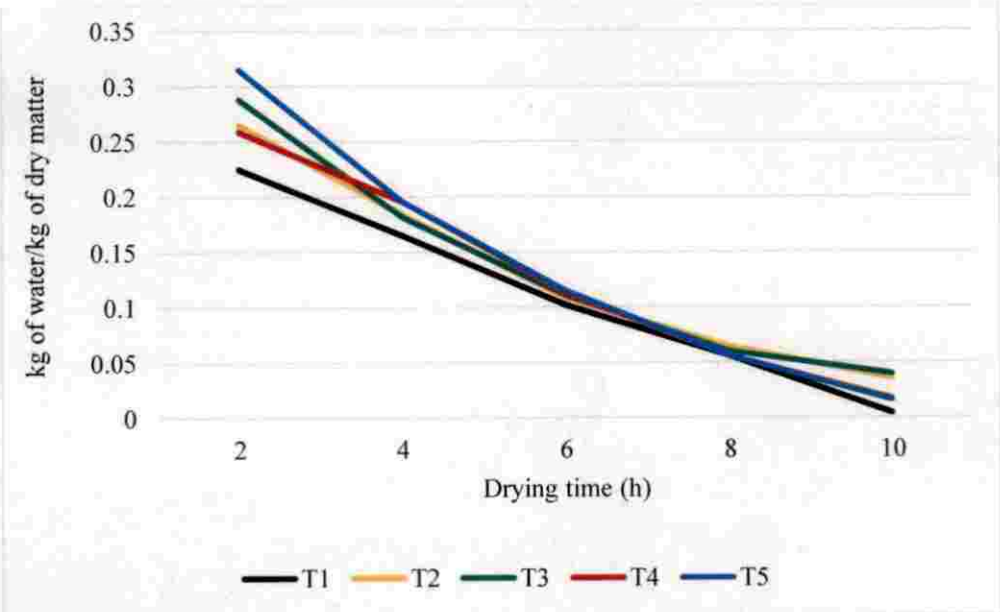


Fig 3. Drying rate of intermediate moisture jackfruit dehydrated at 60 ± 5^0C

4.1.1.4 Colour values

Colour of the product was analysed using Universal Colour Language (UCL) and observations obtained are presented in Table 2. Vivid yellow was the most commonly observed colour in majority of the samples, followed by brilliant yellow. Colour intensity did not vary widely among the samples with respect to pre treatments and dehydration temperature.

Table 2. Colour values of intermediate moisture jackfruit

Treatments	40 ± 5^0C	50 ± 5^0C	60 ± 5^0C
T_1 Calcium lactate + sucrose + AA + KMS	Vivid Yellow(13A)	Brilliant Yellow(13C)	Vivid Yellow (14A)
T_2 Sodium alginate + sucrose + AA + KMS	Light Yellow(12C)	Vivid Yellow(13A)	Vivid Yellow (14A)
T_3 Corn starch + sucrose + AA + KMS	Vivid Yellow(13A)	Brilliant Yellow(13B)	Vivid Yellow (14A)
T_4 Cassava starch + sucrose + AA + KMS	Vivid Yellow(12A)	Vivid Yellow(13A)	Vivid Yellow (14A)
T_5 Control	Vivid Yellow(12A)	Vivid Yellow (14A)	Brilliant Yellow(20A)

AA: ascorbic acid; KMS: Potassium metabisulphite

4.1.2 Biochemical parameters

4.1.2.1 Total Soluble Solids (^{0} Brix)

Addition of sucrose in combination with other food additives, followed by dehydration increased TSS of intermediate moisture jackfruit (Table 3). TSS content of the product in all treatments subjected to additive infusion was significantly higher as compared to the control samples. TSS content of the product in all treatments increased with increase in dehydration temperature. Maximum TSS (67.67) was observed in intermediate moisture jackfruit treated with corn starch and dehydrated at 60 ± 5^0 C and the minimum (8.6) in control samples dehydrated at 40 ± 5^0C. Dehydration at 60 ± 5^0 C resulted in maximum

TSS, irrespective of the treatment combinations. But there was no significant difference among the treatment combinations.

4.1.2.2 Titratable acidity (%)

Immersion of jackfruit in osmotic solution, followed by dehydration resulted in a decrease in acidity of the product (Table 3). Increase in dehydration temperature increased the titratable acidity of all samples. Maximum titratable acidity (0.38) was observed in control sample dehydrated at 60 ± 5^0C and the minimum (0.13) in samples dehydrated at 40 ± 5^0C. However, significant difference in titratable acidity was not observed among the various treatment combinations.

4.1.2.3. Total ash (%)

Dehydration temperature did not have any pronounced effect on ash content of the product. Higher ash content was retained by the control samples at all dehydration temperatures (Table 3). Jackfruit bulbs without any pretreatment (control) dehydrated at 60 ± 5^0C, retained maximum ash content (3.63) and the minimum (1.50) was seen in the bulbs treated with corn starch as the matrix binding agent and dehydrated at 60 ± 5^0C. However significant differences in ash content were not observed among the treatment combinations.

4.1.2.4. pH

The pH of intermediate moisture jackfruit was in the range of 5.48 to 6.35 (Table 3). pH of the product showed a decreasing trend with increase in dehydration temperature. At dehydration temperature of 40 ± 5^0C, all the treatments showed higher pH. Intermediate moisture jackfruit containing cassava starch and dehydrated at 40 ± 5^0C, had the highest pH (6.35) and the lowest (5.55) in the control sample dehydrated at 60 ± 5^0C.

4.1.2.5. Reducing sugars (%)

Reducing sugar content of intermediate moisture jackfruit increased with increase in dehydration temperature (Table 4). Reducing sugar content was in the range of 7.86 to 16.92 %. Intermediate moisture jackfruit containing sodium alginate as the matrix binding agent and dehydrated at 60 ± 5^0C, had maximum reducing sugar content (16.92) and the minimum (7.86) in the control sample dehydrated at 40 ± 5^0C. Reducing sugar content did not vary significantly among the treatment combinations.

4.1.2.6. Non reducing sugars (%)

Non reducing sugars in intermediate moisture jackfruit increased with increase in dehydration temperature (Table 4). Non reducing sugars of the product were significantly higher in jackfruit bulbs subjected to additive infusion before dehydration than the control samples. Non reducing sugar content ranged from 18.29 to 43.59%. Maximum non reducing sugars (43.59) were seen in intermediate moisture jackfruit containing calcium lactate as matrix binding agent and dehydrated at 60 ± 5^0C and the minimum (18.29) in the control sample dehydrated at 40 ± 5^0C. Non reducing sugar content did not vary significantly among the treatment combinations.

4.1.2.7. Total sugars (%)

An increasing trend in total sugar was observed in intermediate moisture jackfruit with increase in dehydration temperature (Table 4). Total sugars of the product were significantly higher in jackfruit bulbs subjected to additive infusion before dehydration than the control samples. Total sugars were maximum (58.76) in intermediate moisture jackfruit containing calcium lactate as matrix binding agent and dehydrated at 60 ± 5^0C and the minimum (26.16) in the control sample dehydrated at 40 ± 5^0C. Significant variation in total sugar content was not observed among the treatment combinations.

4.1.2.8 Ascorbic acid (mg/100 g)

Significant difference in ascorbic acid content was observed among the treatments. Increase in dehydration temperature resulted in the reduction of ascorbic acid in intermediate moisture jackfruit (Table 5). Ascorbic acid content was significantly higher in jackfruit bulbs subjected to pretreatments before dehydration than the control samples which were not subjected to additive infusion. Highest ascorbic acid content (80.83 mg/100 g) was observed in intermediate moisture jackfruit containing sodium alginate and dehydrated at 40 ± 5^0C and the lowest (7.5 mg/100 g) in the control samples dehydrated at 50 ± 5^0C and 60 ± 5^0C.

4.1.2.9 Total carotenoids (mg/100 g)

Increase in dehydration temperature decreased the total carotenoid content of the product (Table 5). Total carotenoid content was the highest (2.85 mg/100 g) in intermediate moisture jackfruit containing corn starch as matrix binding agent and dehydrated at 40 ± 5^0C while the lowest (1.94 mg/100 g) was observed in the control sample dehydrated at 60 ± 5^0C. However significant difference in total carotenoid content was not observed among the treatment combinations.

4.1.2.10 Total flavanoids (mg/100 g)

Decline in the levels of total flavanoids of intermediate moisture jackfruit was seen with increase in dehydration temperature (Table 5). Highest flavanoid content (21.33 mg/100 g) was observed in the product containing corn starch as matrix binding agent and dehydrated at 40 ± 5^0C, while the lowest (11.00) was seen in the control samples dehydrated at 60 ± 5^0C. Significant variation in flavanoid content was not observed among the treatment combinations.

Table 3. Effect of pretreatments and dehydration temperature on biochemical characteristics of intermediate moisture jackfruit

Treatments	TSS (^{0}Brix)			Titratable acidity (%)			Total ash (%)			pH		
	40±5^{0}C	50±5^{0}C	60±5^{0}C	40±5^{0}C	50±5^{0}C	60±5^{0}C	40±5^{0}C	50±5^{0}C	60±5^{0}C	40±5^{0}C	50±5^{0}C	60±5^{0}C
T_1 Calcium lactate + sucrose + AA + KMS	46.27 (6.88)	60.67 (7.85)	63.00 (7.99)	0.13	0.21	0.26	1.55 (1.59)	1.59 (1.61)	1.53 (1.59)	6.25	5.76	5.55
T_2 Sodium alginate + sucrose + AA + KMS	46.13 (6.87)	57.33 (7.63)	66.00 (8.18)	0.13	0.21	0.26	1.63 (1.62)	1.52 (1.59)	1.57 (1.60)	6.27	6.24	5.71
T_3 Corn starch + sucrose + AA + KMS	47.17 (6.94)	53.33 (7.36)	67.67 (8.27)	0.13	0.21	0.26	1.61 (1.62)	1.56 (1.60)	1.50 (1.58)	6.32	6.21	6.13
T_4 Cassava starch + sucrose + AA + KMS	45.20 (6.79)	57.83 (7.68)	65.67 (8.16)	0.13	0.21	0.26	1.51 (1.59)	1.52 (1.59)	1.55 (1.59)	6.35	6.28	6.10
T_5 Control	8.67 (3.11)	11.67 (3.55)	14.33 (3.91)	0.26	0.34	0.38	3.27 (2.07)	3.50 (2.12)	3.63 (2.15)	6.29	6.13	5.48
CD (T)	4.69 (0.33)			0.04			0.15 (0.04)			0.02		
CD (D)	3.63 (0.25)			0.03			NS			0.02		
CD (TXD)	NS			NS			NS			0.04		

AA: ascorbic acid; KMS: Potassium metabisulphite

Table 4. Effect of pretreatments and dehydration temperature on sugar content of intermediate moisture jackfruit

Treatments	Reducing sugars (%)			Non reducing sugars (%)			Total sugars (%)		
	40±5⁰ C	**50±5⁰ C**	**60±5⁰ C**	**40±5⁰ C**	**50±5⁰ C**	**60±5⁰ C**	**40±5⁰ C**	**50±5⁰ C**	**60±5⁰ C**
T_1 Calcium lactate + sucrose + AA + KMS	9.95 (3.31)	10.76 (3.43)	15.17 (4.01)	32.34 (5.77)	36.47 (6.12)	43.59 (6.67)	42.29 (6.58)	47.23 (6.94)	58.76 (7.73)
T_2 Sodium alginate + sucrose + AA + KMS	9.34 (3.22)	11.58 (3.55)	16.92 (4.22)	34.52 (5.96)	35.18 (6.01)	35.67 (6.03)	43.86 (6.69)	46.76 (6.91)	52.59 (7.31)
T_3 Corn starch + sucrose + AA + KMS	9.30 (3.21)	10.89 (3.45)	16.72 (4.20)	33.91 (5.91)	38.05 (6.25)	39.12 (6.33)	43.21 (6.65)	48.94 (7.07)	55.84 (7.54)
T_4 Cassava starch + sucrose + AA + KMS	9.09 (3.17)	10.67 (3.42)	15.86 (4.09)	33.25 (5.85)	35.75 (6.06)	37.84 (6.22)	42.34 (6.58)	46.42 (6.88)	53.70 (7.39)
T_5 Control	7.86 (2.97)	9.27 (3.18)	10.38 (3.36)	18.29 (4.39)	21.64 (4.75)	25.25 (5.12)	26.16 (5.21)	30.90 (5.65)	35.63 (6.05)
CD (T)	1.63(0.22)			3.47 (0.29)			2.59 (0.18)		
CD (D)	1.26(0.17)			2.69 (0.22)			2.00 (0.14)		
CD (TXD)	NS			NS			NS		

AA: ascorbic acid; KMS: Potassium metabisulphite

4.1.3 Microbial population (cfu/g)

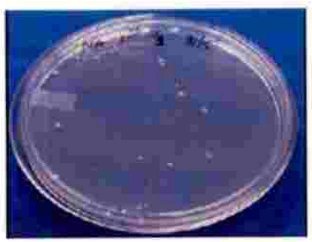
Bacterial population was negligible and within the prescribed limits in intermediate moisture jackfruit (Table 6). Population of bacteria decreased with increase in dehydration temperature. Jackfruit bulbs without any pretreatments (control) had higher bacterial population at all dehydration temperatures. The control samples without any pre-treatment and dehydrated at 40 ± 5^0C had the highest bacterial population (5.0×10^2 cfu/g) while jackfruit bulbs containing calcium lactate and sodium alginate as matrix binding agents and dehydrated at 60 ± 5^0C, had the lowest bacterial population (0.33×10^2 cfu/g).

Fungal population also showed similar trend as that of bacteria. Jackfruit bulbs without any pre-treatment (control) had higher fungal load at all dehydration temperatures. Control sample without any pre-treatment and dehydrated at 40 ± 5^0C had the highest fungal load (4.0×10^3 cfu/g) while intermediate moisture jackfruit containing corn starch, followed by dehydration at 50 ± 5 and 60 ± 5^0C was devoid of fungal population. Intermediate moisture jackfruit containing cassava starch when dehydrated at 60 ± 5^0C, also did not support fungal growth.

None of the samples tested positive for *E.coli.*

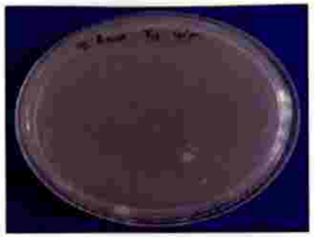
4.1.4 Organoleptic evaluation

Organoleptic properties of intermediate moisture jackfruit subjected to additive infusion were significantly superior to the control samples at all dehydration temperatures (Table 7a, 7b, 7c). Intermediate moisture jackfruit containing corn starch as the matrix binding agent in addition to food additives like sucrose (60%), ascorbic acid (0.2%) and potassium metabisulphite (0.2%) had higher score for organoleptic properties at all dehydration temperatures. Subjecting jackfruit bulbs to additive infusion with these food additives, followed by dehydration at 60 ± 5^0C, gave maximum score in terms of colour, flavour, texture and overall acceptability. Intermediate moisture jackfruit containing cassava starch as the matrix binding agent along with food additives like sucrose, ascorbic acid and potassium metabisulphite was on par with the one containing corn starch as



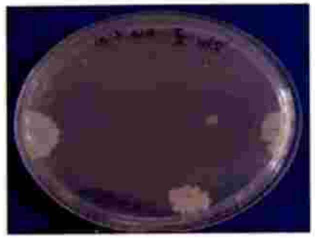
T_1

T_2



T_3

T_4



T_5

Bacterial growth

T_1

T_2

T_3

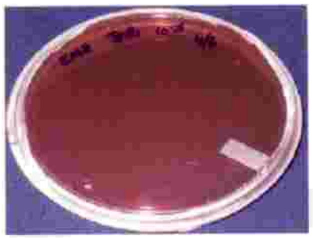
T_4

T_5

Fungal growth

T_1

T_2



T_3

T_4

T_5

E.coli growth

Plate 3. Microbial growth in intermediate moisture jackfruit dehydrated at 60 ± 5^{0}C

matrix binding agent when dehydrated at 40 ± 5^0 and 50 ± 5^0C. However, intermediate moisture jackfruit containing corn starch along with sucrose, ascorbic acid and potassium metabisulphite when dehydrated at 60 ± 5^0C, was significantly superior in organoleptic properties than the other treatment combinations.

Table 5. Effect of pretreatments and dehydration temperature on vitamin C, total carotenoids and total flavanoids of intermediate moisture jackfruit

Treatments	Vitamin C (mg/100g)			Total carotenoids (mg/100g)			Total flavanoids (mg/100g)		
	40±5^{0}C	**50±5^{0}C**	**60±5^{0}C**	**40±5^{0}C**	**50±5^{0}C**	**60±5^{0}C**	**40±5^{0}C**	**50±5^{0}C**	**60±5^{0}C**
T_1 Calcium lactate + sucrose + AA + KMS	69.17 (8.38)	61.67 (7.92)	55.00 (7.48)	2.65	2.62	2.53	19.67 (4.54)	19.33 (4.51)	16.67 (4.20)
T_2 Sodium alginate + sucrose + AA +KMS	80.83 (9.05)	60.83 (7.86)	57.50 (7.64)	2.79	2.71	2.69	15.67 (4.08)	15.00 (3.98)	12.33 (3.61)
T_3 Corn starch + sucrose + AA + KMS	80.00 (9.00)	65.00 (8.12)	63.33 (8.02)	2.85	2.85	2.79	21.33 (4.73)	21.00 (4.69)	18.00 (4.35)
T_4 Cassava starch + sucrose + AA + KMS	79.17 (8.95)	62.50 (7.97)	57.50 (7.64)	2.83	2.73	2.69	20.00 (4.59)	19.33 (4.51)	19.00 (4.47)
T_5 Control	8.33 (3.05)	7.50 (2.92)	7.50 (2.92)	1.99	1.95	1.95	18.00 (4.36)	16.00 (4.11)	11.00 (3.45)
CD (T)	3.20 (0.21)			0.12			2.35(0.29)		
CD (D)	2.48 (0.17)			NS			1.82(0.28)		
CD (TXD)	5.55 (0.37)			NS			NS		

AA: ascorbic acid; KMS: Potassium metabisulphite

Table 6. Effect of pretreatments and dehydration temperature on microbial population of intermediate moisture jackfruit

Treatments	Bacteria (cfu/g) (10^3)			Fungi (cfu/g) (10^2)			*E.coli* (cfu/g) (10^3)		
	40±5^{0}C	**50±5^{0}C**	**60±5^{0}C**	**40±5^{0}C**	**50±5^{0}C**	**60±5^{0}C**	**40±5^{0}C**	**50±5^{0}C**	**60±5^{0}C**
T_1 Calcium lactate + sucrose + AA +KMS	2.000	0.67	0.33	0.67	0.33	0.33	ND	ND	ND
T_2 Sodium alginate + sucrose + AA + KMS	1.333	1.00	0.33	0.67	0.33	0.33	ND	ND	ND
T_3 Corn starch + sucrose + AA + KMS	1.667	1.00	0.67	0.33	0.00	0.00	ND	ND	ND
T_4 Cassava starch + sucrose + AA + KMS	2.000	0.67	0.67	0.67	0.33	0.00	ND	ND	ND
T_5 Control	5.000	4.33	3.67	4.00	3.00	2.67	ND	ND	ND
CD (T)	1.28(0.38)			0.95(0.30)					
CD (D)	0.99(0.29)			NS					
CD (TXD)	NS			NS					

AA: ascorbic acid; KMS: Potassium metabisulphite ND: Not detected

Table 7a. Mean sensory scores for the intermediate moisture jackfruit dehydrated at 40 ± 5^{0}C

Samples	Appearance	Colour	Flavour	Texture	Odour	Taste	After taste	Overall acceptability	Total score
T_1	6.60	7.00	6.20	6.40	6.60	6.90	6.50	6.80	53.00
T_2	7.00	7.50	5.50	6.30	6.30	5.70	5.80	6.00	50.10
T_3	7.60	7.60	7.70	7.60	7.40	7.90	7.90	8.10	61.80
T_4	7.60	7.50	7.45	7.40	7.40	7.50	7.10	7.80	59.75
T_5	5.10	5.10	4.70	5.00	4.90	4.10	4.35	4.10	37.35
Kendall's W test	0.74	0.68	0.78	0.78	0.67	0.91	0.89	0.87	

T_1 : Calcium lactate + sucrose + ascorbic acid + KMS

T_2 : Sodium alginate + sucrose + ascorbic acid + KMS

T_3 : Corn starch + sucrose + ascorbic acid + KMS

T_4 : Cassava starch + sucrose + ascorbic acid + KMS

T_5 : Control

Table 7b. Mean sensory scores for the intermediate moisture jackfruit dehydrated at 50 ± 5^{0}C

Samples	Appearance	Colour	Flavour	Texture	Odour	Taste	After taste	Overall acceptability	Total score
T_1	6.90	7.00	6.70	6.25	6.40	6.55	6.00	6.90	52.70
T_2	6.75	6.90	6.30	6.20	6.70	5.75	5.85	5.70	50.15
T_3	7.60	7.70	7.60	7.85	7.30	7.90	7.60	7.70	61.25
T_4	7.45	7.60	7.10	7.20	7.00	7.20	7.05	7.05	57.65
T_5	5.30	4.80	4.70	4.40	4.50	4.20	4.10	3.80	35.80
Kendall's W test	0.64	0.71	0.71	0.63	0.61	0.66	0.69	0.71	

T_1 : Calcium lactate + sucrose + ascorbic acid + KMS

T_2 : Sodium alginate + sucrose + ascorbic acid + KMS

T_3 : Corn starch + sucrose + ascorbic acid + KMS

T_4 : Cassava starch + sucrose + ascorbic acid + KMS

T_5 : Control

Table.7c. Mean sensory scores for the intermediate moisture jackfruit dehydrated at 60 ± 5^{0}C

Samples	Appearance	Colour	Flavour	Texture	Odour	Taste	After taste	Overall acceptability	Total score
T_1	7.00	7.20	7.00	6.40	6.90	7.00	7.00	7.10	55.60
T_2	6.90	6.80	6.80	6.30	7.20	6.90	6.90	6.80	54.60
T_3	7.65	7.40	7.80	7.70	7.50	8.20	7.90	8.30	62.45
T_4	7.70	7.70	7.60	7.50	7.50	7.90	7.50	8.10	61.50
T_5	5.30	5.30	4.80	4.30	5.50	4.90	5.20	5.20	40.50
Kendall's W test	0.60	0.36	0.41	0.67.201	0.42	0.72	0.69	0.80	

T_1 : Calcium lactate + sucrose + ascorbic acid + KMS

T_2 : Sodium alginate + sucrose + ascorbic acid + KMS

T_3 : Corn starch + sucrose + ascorbic acid + KMS

T_4 : Cassava starch + sucrose + ascorbic acid + KMS

T_5 : Control

4.2 Effect of packaging materials and storage temperature on quality of intermediate moisture jackfruit

Statistical analysis of the quality parameters of intermediate moisture jackfruit developed through various treatment combinations revealed significant difference with respect to only vitamin C and pH. Therefore, the best one among the five treatments was selected based on microbial quality and organoleptic properties. Dehydration temperature for the production of intermediate moisture jackfruit at 60 ± 5^0C resulted in minimum microbial load in the product with respect to bacteria and fungi. *E.coli* was not detected in any of the samples. With respect to organoleptic properties, intermediate moisture jackfruit containing corn starch (2%) as the matrix binding agent had maximum score for colour, flavour, texture and overall acceptability at all dehydration temperatures. Therefore, jackfruit bulbs treated with corn starch (2%), sucrose (60%), ascorbic acid (0.2%) and potassium metabisulphite (0.2%), followed by dehydration at 60 ± 5^0C was selected as the best treatment combination for the development of intermediate moisture jackfruit with the intention of having minimum microbial load and maximum organoleptic acceptability.

The product thus developed was packed in seven different types of packaging materials and was stored at two different levels of temperature (ambient and refrigeration). Observations were recorded at an interval of two months during storage. The packaging materials used for storage studies are as follows:

T_1: Low density polyethylene pouches (LDPE 100 gauge)

T_2: Low density polyethylene pouches (LDPE 200 gauge)

T_3: Plastic trays over wrapped with cling film

T_4: High impact polystyrene boxes (HIPS)

T_5: Laminated aluminium foil pouches

T_6: Rigid plastic boxes

T_7: Glass containers

LDPE 100 gauge

LDPE 200 gauge

Plastic tray overwrapped with cling film

High impact polystyrene boxes

Laminated aluminimum foil pouches

Rigid plastic box

Glass jar

Plate 4. Intermediate moisture jackfruit enclosed in various packaging materials

4.2.1 Physical characteristics

4.2.1.1. Moisture (%)

Moisture content of intermediate moisture jackfruit showed a declining trend throughout the storage period (Table 8). Intermediate moisture jackfruit stored under refrigerated condition had higher moisture content in all the packaging materials. Intermediate moisture jackfruit stored in glass jar under refrigerated condition retained maximum moisture (13.67) and the minimum (9.50) in LDPE 100 gauge bags, after a period of six months.

4.2.1.2 Water activity

Water activity of intermediate moisture jackfruit decreased during storage period (Table 9). Reduction in water activity was more under ambient conditions than under refrigerated condition. However, the reduction in water activity over a period of six months of storage was insignificant with respect to type of packaging material and storage temperature. After six months of storage, water activity of the samples in all the packaging materials was on par.

4.2.1.3 Equilibrium Relative Humidity and Critical Moisture Point

The data on relationship between equilibrium moisture content and number of days to reach the equilibrium at a particular relative humidity are presented in Table 10. The humidity-moisture equilibrium curve is given in Fig 4.

Intermediate moisture jackfruit retained its normal quality below 64.3 per cent relative humidity. The product showed colour change at 64.3 per cent relative humidity. Fungal growth was observed at a relative humidity of 75.8 per cent and above. The optimum relative humidity for the product was found to be below 64.3 per cent for safe storage and shelf life. The critical moisture point of intermediate moisture jackfruit was 16.

Table 8. Effect of packaging materials and storage temperature on moisture content (%) of intermediate moisture jackfruit

Treatments	Moisture content (%)				
	Initial	2MAS		4MAS	6MAS
		Ambient	Refrigerated	Refrigerated	Refrigerated
T_1	16.80	13.26* (3.77)	13.33 (3.78)	11.67	9.50
T_2	16.80	12.09* (3.61)	14.10 (3.88)	13.00	10.33
T_3	16.80	13.20* (3.77)	14.17 (3.89)	13.20	11.50
T_4	16.80	14.00* (3.867)	14.23 (3.89)	13.67	12.33
T_5	16.80	12.04* (3.61)	14.77 (3.97)	13.33	10.53
T_6	16.80	10.07* (3.32)	13.90 (3.86)	12.67	10.47
T_7	16.80	14.55* (3.94)	16.26 (4.14)	14.67	13.67
CD		NS		NS	2.02

MAS: Months after storage

* Unmarketable ** Values in bracket are transformed values

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

Table 9. Effect of packaging materials and storage temperature on water activity of intermediate moisture jackfruit

Treatments	Water activity				
	Initial	2MAS		4MAS	6MAS
		Ambient	Refrigerated	Refrigerated	Refrigerated
T_1	0.76	0.73* (1.32)	0.75 (1.32)	0.74 (1.32)	0.74 (1.32)
T_2	0.76	0.73* (1.31)	0.75 (1.32)	0.72 (1.31)	0.72 (1.31)
T_3	0.76	0.68* (1.30)	0.753 (1.32)	0.75 (1.32)	0.74 (1.32)
T_4	0.76	0.73* (1.32)	0.75 (1.32)	0.74 (1.32)	0.74 (1.32)
T_5	0.76	0.74* (1.32)	0.75 (1.33)	0.75 (1.32)	0.74 (1.32)
T_6	0.76	0.73* (1.32)	0.75 (1.32)	0.73 (1.32)	0.73 (1.31)
T_7	0.76	0.74* (1.32)	0.76 (1.33)	0.75 (1.32)	0.74 (1.32)
CD		0.03 (0.01)		NS	NS

MAS: Months after storage

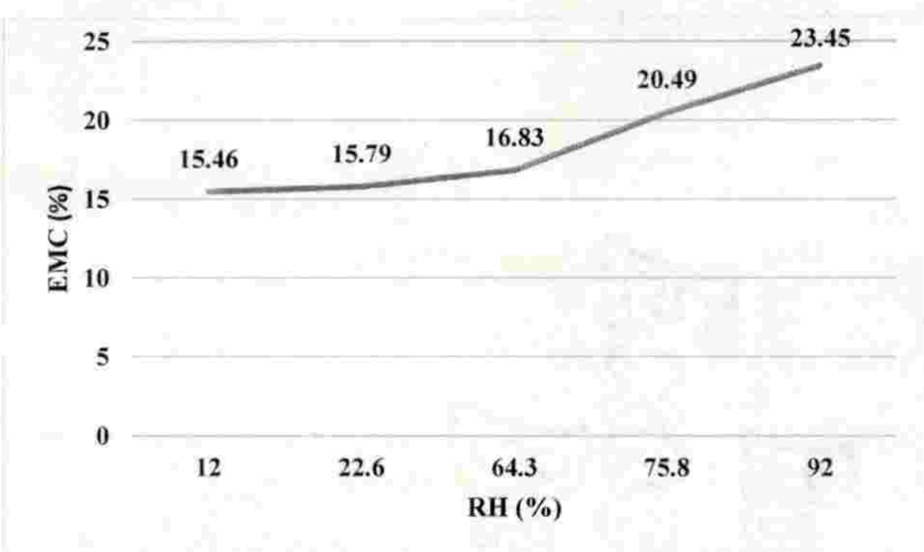
* Unmarketable ** Values in bracket are transformed values

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

Table 10. Equilibrium relative humidity of intermediate moisture jackfruit

RH (%)	EMC (%)	No. of days to reach equilibrium	Remarks
12.0	15.46	30	Normal
22.6	15.79	25	Normal
64.3	16.83	15	Slight colour change
75.8	20.49	12	Fungal growth
92.0	23.45	7	Fungal growth

Fig 4. Pattern of equilibrium relative humidity in intermediate moisture jackfruit



4.2.1.4 Colour values

Intermediate moisture jackfruit stored under refrigerated condition showed minimum loss in its colour throughout the storage period (Table 11). Samples stored in LDPE 100 gauge, LDPE 200 gauge, laminated aluminium foil pouches and glass jars showed maximum retention of colour during storage period. Treatments stored under ambient conditions showed higher variation in colour after two months of storage. Treatments packed in plastic trays overwrapped with cling film showed minimum variation in colour during storage. Samples packed in plastic trays overwrapped with cling film, high impact polystyrene boxes and rigid plastic boxes showed darkening at the end of storage period.

4.2.2 Biochemical parameters

4.2.2.1 Total Soluble Solids (^{0}Brix)

TSS content of intermediate moisture jackfruit showed an upward trend during storage (Table 12). After two months of storage, intermediate moisture jackfruit kept under ambient temperature retained higher TSS as compared to refrigerated storage, in all packaging materials. After six months of storage, intermediate moisture jackfruit stored in glass jars under refrigerated condition retained maximum TSS (78.9) and the minimum (54.5) was seen in the one packed in plastic tray overwrapped with cling film.

4.2.2.2 Titratable acidity (%)

An increasing trend in titratable acidity was seen in intermediate moisture jackfruit during storage in all the packaging materials, irrespective of the storage atmosphere (Table 13). Titratable acidity was higher under ambient temperature than at low temperature. After six months of storage, intermediate moisture jackfruit packed in plastic tray overwrapped with cling film had the highest (0.51) titratable acidity while the lowest (0.34) was seen in the samples packed in laminated aluminium foil pouches and glass containers. However, significant

T_1 T_2 T_3 T_4 T_5 T_6 T_7

Ambient condition

T_1 T_2 T_3 T_4 T_5 T_6 T_7

Refrigerated condition

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

Plate 5. Quality of intermediate moisture jackfruit in various packaging materials, two months after storage under ambient and refrigerated conditions.

T$_1$ T$_2$ T$_3$ T$_4$ T$_5$ T$_6$ T$_7$

4MAS

T$_1$ T$_2$ T$_3$ T$_4$ T$_5$ T$_6$ T$_7$

6MAS

Plate 6. Quality of intermediate moisture jackfruit in various packaging materials, four and six months after storage under refrigerated condition

[T$_1$: LDPE 100 gauge T$_2$: LDPE 200 gauge T$_3$: Plastic trays over wrapped with cling film T$_4$: High impact polystyrene boxes (HIPS) T$_5$: Laminated aluminium foil pouches T$_6$: Rigid plastic boxes T$_7$: Glass containers] variation in titratable acidity was not found in the samples with respect to packaging materilas and storage temperature.

4.2.2.3. Total ash (%)

An increasing trend in ash content was seen in intermediate moisture jackfruit in all the packaging materials (Table 14). Ash content was higher at ambient temperature than at low temperature after two months of storage. Higher ash content (2.57) was seen in the sample packed in glass container while the lowest (2.27) was seen in the one packed in laminated aluminium foil pouch, after six months of storage period. Significant variation in ash content was not observed in the samples with respect to type of packaging material and storage temperature.

4.2.2.4. pH

pH decreased during storage (Table 15). The decrease in pH was more under ambient temperature than under refrigerated condition. After two months of storage, intermediate moisture jackfruit packed in LDPE (100 gauge) and stored under refrigerated condition had the highest pH (6.64) and the one packed in rigid plastic box and stored under ambient conditions had the lowest (6.02). However, after six months of storage period, intermediate moisture jackfruit packed in glass container and stored under refrigerated condition had maximum pH (5.98).

4.2.2.5 Sugars (%)

An upward trend was noticed in reducing sugar content of samples, irrespective of packaging material (Table 16). The rise in reducing sugars was more at ambient temperature than at low temperature, after two months of storage. After six months of storage, intermediate moisture jackfruit packed in plastic tray, overwrapped with cling film had significantly higher reducing sugar content (38.99) and the lowest (24.91) was seen in the sample packed in glass container. Contrast to reducing sugars, non-reducing sugars fell during storage

(Table 17). After two months of storage, samples stored under refrigerated condition retained higher non reducing sugars than the ones stored under ambient conditions. After a period of six months, significant difference in non-reducing sugar content was not seen in the samples with respect to the type of packaging material. However, intermediate moisture jackfruit packed in LDPE (200 gauge) had the highest non reducing sugar (36.83) while the lowest (31.56) was seen in the one packed in plastic trays overwrapped with cling film.

Total sugars in intermediate moisture jackfruit rose during storage (Table 18). The rise in total sugars was more under ambient conditions than under refrigerated conditions, after two months of storage. Intermediate moisture jackfruit packed in plastic tray overwrapped with cling film had the highest (70.55) total sugars while the samples packed in glass container had the lowest (61.41), after six months of storage.

4.2.2.6 Ascorbic acid content (mg 100 g^{-1})

Ascorbic acid content of all samples decreased throughout the storage period (Table 19). Packaging materials did not have any significant influence on ascorbic acid content of intermediate jackfruit during the first two months of storage. Intermediate moisture jackfruit stored under refrigerated condition in all packaging materials retained significantly higher ascorbic acid content as compared to the samples kept under ambient conditions. After six months of storage, samples packed in LDPE 100 gauge had the highest (43.66) ascorbic acid content and the lowest (27.53) was seen in the ones packed in rigid plastic boxes.

Table 11. Effect of packaging materials and storage temperature on colour of intermediate moisture jackfruit

Treatments	Colour				
	Initial	2MAS		4MAS	6MAS
		Ambient	Refrigerated		
T_1	Vivid Yellow (14A)	Brilliant Greenish Yellow(7C)*	Brilliant Greenish Yellow(6C)	Brilliant Greenish Yellow(6C)	Brilliant Greenish Yellow(6C)
T_2	Vivid Yellow (14A)	Light Greenish Yellow(7D)*	Brilliant Greenish Yellow(6B)	Brilliant Greenish Yellow(6B)	Brilliant Greenish Yellow(6B)
T_3	Vivid Yellow (14A)	Brilliant Yellow(7A)*	Vivid Yellow(13A)	Brilliant Yellow(13B)	Brilliant Yellow(10A)
T_4	Vivid Yellow (14A)	Brilliant Yellow(7A)*	Vivid Yellow (14A)	Vivid Yellow (14A)	Vivid Yellow (14A)
T_5	Vivid Yellow (14A)	Brilliant Yellow(7A)*	Vivid Yellow(13A)	Brilliant Yellow(13B)	Brilliant Yellow(13C)
T_6	Vivid Yellow (14A)	Brilliant Yellow(7A)*	Brilliant Yellow(10A)	Brilliant Yellow(11A)	Brilliant Yellow(12B)
T_7	Vivid Yellow (14A)	Brilliant Yellow(7A)*	Vivid Yellow (12A)	Vivid Yellow (12A)	Vivid Yellow (12A)

MAS: Months after storage

* Unmarketable ** Values in bracket are transformed values

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

Table 12. Effect of packaging materials and storage temperature on TSS (^{0}Brix) of intermediate moisture jackfruit

Treatments	TSS (^{0} Brix)				
	Initial	2MAS		4MAS	6MAS
		Ambient	Refrigerated	Refrigerated	Refrigerated
T_1	46.83	52.33* (7.30)	50.43 (7.16)	54.87 (7.47)	55.77 (7.53)
T_2	46.83	51.23* (7.22)	48.60 (7.04)	53.70 (7.39)	55.87 (7.54)
T_3	46.83	51.70* (7.26)	49.83 (7.12)	53.90 (7.41)	54.50 (7.45)
T_4	46.83	70.63* (8.46)	69.80 (8.41)	72.87 (8.59)	74.70 (8.70)
T_5	46.83	68.60* (8.34)	65.93 (8.18)	70.23 (8.43)	72.83 (8.59)
T_6	46.83	68.53* (8.34)	67.00 (8.25)	70.27 (8.44)	71.80 (8.53)
T_7	46.83	75.57* (8.75)	73.13 (8.61)	76.43 (8.79)	78.90 (8.94)
CD		NS		6.30 (0.39)	6.42 (0.40)

MAS: Months after storage * Unmarketable ** Values in bracket are transformed values

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

Table 13. Effect of packaging materials and storage temperature on titratable acidity (%) of intermediate moisture jackfruit

Treatments	Titratable acidity (%)				
	Initial	2MAS		4MAS	6MAS
		Ambient	Refrigerated	Refrigerated	Refrigerated
T_1	0.26	0.29* (1.14)	0.28 (1.13)	0.34 (1.16)	0.38 (1.18)
T_2	0.26	0.28* (1.13)	0.29 1.14)	0.38 (1.80)	0.47 (1.21)
T_3	0.26	0.38* (1.18)	0.34 (1.16)	0.43 (1.19)	0.51 (1.23)
T_4	0.26	0.34* (1.16)	0.29 (1.14)	0.34 (1.15)	0.38 (1.18)
T_5	0.26	0.29* (1.14)	0.28 (1.13)	0.29 (1.14)	0.34 (1.16)
T_6	0.26	0.38* (1.18)	0.34 (1.16)	0.38 (1.18)	0.43 (1.19)
T_7	0.26	0.28* (1.13)	0.27 (1.12)	0.29 (1.14)	0.34 (1.16)
CD		NS		NS	NS

MAS: Months after storage

* Unmarketable ** Values in bracket are transformed values

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

Table 14. Effect of packaging materials and storage temperature on total ash (%) of intermediate moisture jackfruit

Treatments	Total ash (%)				
	Initial	2MAS		4MAS	6MAS
		Ambient	Refrigerated	Refrigerated	Refrigerated
T_1	1.64	2.04*	1.84	2.23	2.40
T_2	1.64	1.97*	1.88	2.16	2.50
T_3	1.64	1.99*	1.77	2.10	2.40
T_4	1.64	2.12*	1.97	2.13	2.37
T_5	1.64	1.99*	1.83	2.07	2.27
T_6	1.64	2.00*	1.97	2.37	2.50
T_7	1.64	2.09*	1.92	2.23	2.57
CD		NS		NS	NS

MAS: Months after storage

* Unmarketable ** Values in bracket are transformed values

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

Table 15. Effect of packaging materials and storage temperature on pH of intermediate moisture jackfruit

Treatments	pH				
	Initial	2MAS		4MAS	6MAS
		Ambient	Refrigerated	Refrigerated	Refrigerated
T_1	6.66	6.61*	6.64	6.59	5.60
T_2	6.66	6.07*	6.25	6.20	5.96
T_3	6.66	6.05*	6.31	6.26	5.79
T_4	6.66	6.05*	6.41	6.38	5.73
T_5	6.66	6.08*	6.16	6.10	5.94
T_6	6.66	6.02*	6.07	5.99	5.92
T_7	6.66	6.36*	6.24	6.19	5.98
CD		0.06		0.08	0.06

MAS: Months after storage

* Unmarketable ** Values in bracket are transformed values

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

Table 16. Effect of packaging materials and storage temperature on reducing sugars of intermediate moisture jackfruit

Treatments	Reducing sugars (%)				
	Initial	2MAS		4MAS	6MAS
		Ambient	Refrigerated	Refrigerated	Refrigerated
T_1	16.72	25.83* (5.18)	19.94 (4.58)	23.83 (4.98)	26.75 (5.27)
T_2	16.72	24.77* (5.08)	21.29 (4.72)	25.92 (5.19)	27.78 (5.36)
T_3	16.72	27.98* (5.38)	20.27 (4.61)	34.18 (5.93)	38.99 (6.32)
T_4	16.72	25.16* (5.11)	18.66 (4.43)	23.69 (4.97)	27.83 (5.47)
T_5	16.72	27.13* (5.30)	20.83 (4.67)	25.54 (5.15)	28.91 (5.56)
T_6	16.72	29.49* (5.52)	22.49 (4.85)	25.62 (5.16)	29.95 (5.07)
T_7	16.72	22.88* (4.88)	19.58 (4.54)	22.63 (4.86)	24.91 (0.35)
CD		2.44 (0.24)		3.61 (0.35)	3.55 (0.05)

MAS: Months after storage * Unmarketable ** Values in bracket are transformed values

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

Table 17. Effect of packaging materials and storage temperature on non-reducing sugars of intermediate moisture jackfruit

Treatments	Non-reducing sugars (%)				
	Initial	2MAS		4MAS	6MAS
		Ambient	Refrigerated	Refrigerated	Refrigerated
T_1	39.11	36.19* (6.09)	38.02 (6.25)	37.03 (6.17)	36.6 (6.47)
T_2	39.11	36.61* (6.13)	38.18 (6.26)	37.77 (6.23)	36.83 (6.10)
T_3	39.11	32.69* (5.80)	35.56 (6.05)	33.42 (5.87)	31.56 (5.77)
T_4	39.11	36.12* (6.09)	38.80 (6.31)	36.26 (6.09)	34.97 (6.84)
T_5	39.11	35.57* (6.05)	37.62 (6.22)	36.17 (6.09)	35.62 (6.26)
T_6	39.11	35.83* (6.07)	37.90 (6.24)	36.8 (6.15)	35.47 (6.39)
T_7	39.11	36.29* (6.11)	38.24 (6.26)	37.03 (6.17)	36.5 (6.27)
CD		NS		NS	3.16 (0.06)

MAS: Months after storage

* Unmarketable ** Values in bracket are transformed values

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

Table 18. Effect of packaging materials and storage temperature on total sugars of intermediate moisture jackfruit

Treatments	Total sugars (%)				
	Initial	2MAS		4MAS	6MAS
		Ambient	Refrigerated	Refrigerated	Refrigerated
T_1	55.83	62.08* (7.94)	57.96 (7.67)	60.87 (7.87)	63.36 (8.02)
T_2	55.83	61.39* (7.89)	59.46 (7.77)	63.68 (8.04)	64.61 (8.10)
T_3	55.83	66.63* (8.22)	63.55 (8.03)	67.6 (8.28)	70.55 (8.46)
T_4	55.83	61.28* (7.98)	57.46 (7.65)	59.95 (7.81)	62.71 (7.98)
T_5	55.83	62.70* (7.98)	58.45 (7.71)	61.70 (7.92)	64.53 (8.09)
T_6	55.83	65.32* (8.14)	60.39 (7.83)	62.42 (7.96)	65.43 (8.15)
T_7	55.83	59.17* (7.76)	57.83 (7.67)	59.66 (7.79)	61.41 (7.90)
CD		NS		3.06 (0.19)	3.06 (0.19)

MAS: Months after storage

* Unmarketable ** Values in bracket are transformed values

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7 : Glass containers]

Table 19. Effect of packaging materials and storage temperature on ascorbic acid content (mg/100g) of intermediate moisture jackfruit

Treatments	Vitamin C (mg/100g)				
	Initial	2MAS		4MAS	6MAS
		Ambient	Refrigerated	Refrigerated	Refrigerated
T_1	63.33	42.50* (6.59)	60.00 (7.81)	53.49 (7.38)	43.66 (6.68)
T_2	63.33	37.50* (6.19)	55.83 (7.54)	49.56 (7.11)	38.94 (6.31)
T_3	63.33	38.33* (6.25)	50.00 (7.12)	44.84 (6.76)	35.40 (6.03)
T_4	63.33	33.33* (5.82)	50.83 (7.14)	45.61 (6.82)	35.01 (5.99)
T_5	63.33	44.17* (6.72)	54.17 (7.41)	46.02 (6.85)	38.94 (6.32)
T_6	63.33	32.50* (5.77)	49.83 (7.10)	38.55 (6.28)	27.53 (5.32)
T_7	63.33	49.56* (7.11)	57.50 (7.63)	49.95 (7.13)	41.30 (6.50)
CD		NS		8.46 (0.62)	7.63 (0.65)

MAS: Months after storage

* Unmarketable ** Values in bracket are transformed values

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

4.2.2.7 Total carotenoids (mg 100 g^{-1})

Total carotenoid content of intermediate moisture jackfruit showed a declining trend during storage, irrespective of packaging material and storage condition (Table 20).The decline was more under ambient conditions than under refrigerated conditions, after two months of storage. Total carotenoids were maximum (2.98) in the sample packed in glass container and the minimum (2.39) was seen in the samples packed in both LDPE 200 gauge and plastic tray overwrapped with cling film, after six months of storage period.

Table 20. Effect of packaging materials and storage temperature on total carotenoids (mg/100g) of intermediate moisture jackfruit

Treatments	Total carotenoids(mg/100g)				
	Initial	2MAS		4MAS	6MAS
		Ambient	Refrigerated	Refrigerated	Refrigerated
T_1	3.26	2.85*	3.10	3.01	2.94
T_2	3.26	2.28*	2.48	2.44	2.39
T_3	3.26	2.08*	2.68	2.59	2.39
T_4	3.26	2.34*	3.00	2.99	2.93
T_5	3.26	2.57*	2.94	2.83	2.82
T_6	3.26	2.43*	2.89	2.80	2.74
T_7	3.26	2.53*	3.16	3.09	2.98
CD		0.04		0.03	0.05

MAS: Months after storage

* Unmarketable ** Values in bracket are transformed values

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

4.2.2.8 Total flavanoids (mg 100 g^{-1})

Flavanoids in intermediate moisture jackfruit declined throughout the storage period (Table 21). The fall in flavanoid content was more under ambient conditions of storage than under refrigerated storage. However, flavanoid content of intermediate moisture jackfruit did not reveal significant variation with regard to the combined effect of type of packaging material and storage temperature. After six months of storage, maximum flavanoid retention (15.00) was seen in the product packed in LDPE 100 gauge and the minimum (11.67) in the sample packed in plastic tray overwrapped with cling film.

4.2.2.9 Non enzymatic browning (Absorbance)

Non enzymatic browning of intermediate moisture jackfruit increased throughout the storage period (Table 22). All samples stored under refrigerated conditions, irrespective of the packaging material showed significantly lower non enzymatic browning as compared to the ones kept under ambient conditions. After two months of storage, minimum non enzymatic browning (0.180) was seen in the samples kept in LDPE 100 gauge and glass container. After six months of storage period, while the maximum non enzymatic browning (0.270) was observed in the samples stored in plastic trays overwrapped with cling film which was on par with the samples in LDPE 200 gauge (0.260) and HIPS boxes (0.250).

4.2.2.12 Shelf life

Intermediate moisture jackfruit stored under ambient conditions had a shorter shelf life when compared to that stored under refrigerated condition. All the treatments kept under ambient temperature became unmarketable before two months of storage (Table 23). Treatments showed browning after one month of storage and completely spoiled after 75 days. Intermediate moisture jackfruit stored in plastic tray overwrapped with cling film showed minimum shelf life (50 days) while that stored in glass container showed maximum shelf life (62.33 days) under ambient conditions. Intermediate moisture jackfruit stored under refrigerated condition in HIPS, LDPE 100 gauge and glass container had better shelf life than other treatments. They remained marketable upto 7 months.

Table 21. Effect of packaging materials and storage temperature on total flavanoids (mg/100g) of intermediate moisture jackfruit

Treatments	Total flavanoids (mg/100g)				
	Initial	2MAS		4MAS	6MAS
		Ambient	Refrigerated	Refrigerated	Refrigerated
T_1	18.00	14.67* (3.96)	16.00 (4.12)	15.67	15.00
T_2	18.00	13.67* (3.83)	15.33 (3.04)	15.00	14.33
T_3	18.00	11.33* (3.50)	12.67 (3.69)	12.33	11.67
T_4	18.00	14.33* (3.91)	16 (4.11)	15.67	14.67
T_5	18.00	14.67* (3.96)	15.67 (4.08)	15.33	14.33
T_6	18.00	12.67* (3.69)	14.00 (3.86)	13.67	12.67
T_7	18.00	15.33* (4.04)	16.00 (4.12)	15.67	14.67
CD		NS		NS	NS

MAS: Months after storage

* Unmarketable ** Values in bracket are transformed values [T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

Table 22. Effect of packaging materials and storage temperature on non-enzymatic browning (absorbance) of intermediate moisture jackfruit

Treatments	Non enzymatic browning (absorbance)				
	Initial	2MAS		4MAS	6MAS
		Ambient	Refrigerated	Refrigerated	Refrigerated
T_1	0.13	0.21*	0.16	0.18 (1.08)	0.18 (1.09)
T_2	0.13	0.25*	0.19	0.22 (1.10)	0.26 (1.12)
T_3	0.13	0.29*	0.19	0.24 (1.12)	0.27 (1.13)
T_4	0.13	0.24*	0.18	0.20 (1.10)	0.25 (1.12)
T_5	0.13	0.26*	0.17	0.17 (1.08)	0.19 (1.09)
T_6	0.13	0.25*	0.18	0.19 (1.09)	0.24 (1.11)
T_7	0.13	0.20*	0.16	0.17 (1.08)	0.18 (1.09)
CD		0.02		0.02 (0.01)	0.02 (0.01)

MAS: Months after storage

* Unmarketable ** Values in bracket are transformed values

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

Table 23. Shelflife of intermediate moisture jackfruit packed in different packaging materials

Treatments	Storage condition	
	Ambient (Days)	Refrigerated (Days)
T_1	58.00	180.00
T_2	58.33	180.00
T_3	50.00	165.00
T_4	57.00	176.33
T_5	57.33	182.33
T_6	56.67	180.00
T_7	62.33	185.33
CD (T)	4.9	
CD (S)	2.6	
CD (T X S)	NS	

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

4.2.3 Microbial population (cfu/g)

Bacterial load of intermediate moisture jackfruit immediately after preparation was low (0.33×10^2 cfu/g), which was within acceptable limits and continued to remain so during the storage period (Table 24). Significant varition in bacterial load was not seen in the samples with respect to packaging material and storage temperature. However, samples kept under ambient condition had higher bacterial load as compared to the ones stored under refrigerated condition. Bacterial population did not show significant proliferation during storage. After six months of storage under refrigerated conditions, samples packed in plastic tray overwrapped with cling film had maximum bacterial population (3.67×10^2) while the minimum (2.0×10^2) was seen in the ones packed in laminated aluminium foil pouches.

Initial fungal load was also low (1.33×10^3) (Table 25) . Fungal proliferation on all samples was lower under refrigerated condition as compared to the ones under ambient conditions. Significant variation in fungal load was not observed in the samples with regard to packaging material and storage condition. At the end of the storage period under refrigerated condition, the product packed in plastic tray overwrapped with cling film had maximum (4.0 x 10^3) fungal load while the samples packed in LDPE 200 gauge and rigid plastic box had the minimum (2.0 x 10^3). *Escherechia coli* was not detected initially and also throughout the storage period.

4.2.4 Organoleptic evaluation

Score for organoleptic attributes showed a declining trend throughout the storage period, irrespective of packaging material and storage temperature (Table 26a, 26b, 26c, 26d). The deterioration in organoleptic properties was more under ambient conditions than under refrigerated condition.

Table 24. Effect of packaging materials and storage temperature on bacterial population (10^2 cfu/g) of intermediate moisture jackfruit

Treatments	Bacterial population (10^2 cfu/g)				
	Initial	2MAS		4MAS	6MAS
		Ambient	Refrigerated	Refrigerated	Refrigerated
T_1	0.33	3.33*	1.67	1.00	2.33
T_2	0.33	2.00*	1.00	1.67	2.00
T_3	0.33	3.67*	2.33	3.33	4.00
T_4	0.33	2.67*	1.67	2.33	3.00
T_5	0.33	2.33*	0.33	2.00	2.67
T_6	0.33	3.00*	1.00	1.33	2.00
T_7	0.33	2.33*	0.67	1.67	2.33
CD		0.59		1.28	NS

Table 25. Effect of packaging materials and storage temperature on fungal population (10^3 cfu/g) of intermediate moisture jackfruit

Treatments	Fungal population (10^3 cfu/g)				
	Initial	2MAS		4MAS	6MAS
		Ambient	Refrigerated	Refrigerated	Refrigerated
T_1	1.33	1.67*	0.33	1.00	2.33
T_2	1.33	1.67*	0.67	1.67	2.00
T_3	1.33	2.33*	2.00	3.33	4.00
T_4	1.33	2.33*	1.33	2.33	3.00
T_5	1.33	2.00*	1.67	2.00	2.67
T_6	1.33	1.67*	0.67	1.33	2.00
T_7	1.33	1.67*	0.67	1.67	2.33
CD		NS		1.28	NS

MAS: Months after storage * Unmarketable ** Values in bracket are transformed values [T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

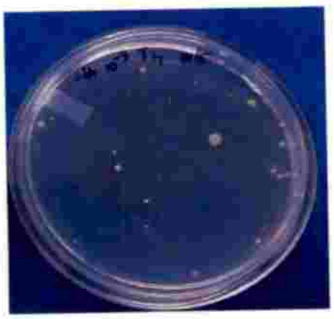
MAS: Months after storage * Unmarketable ** Values in bracket are transformed values

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

T1

T2

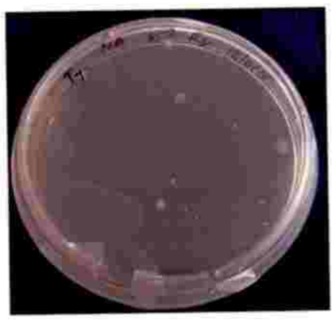
T3



T4

T5

T6



T7

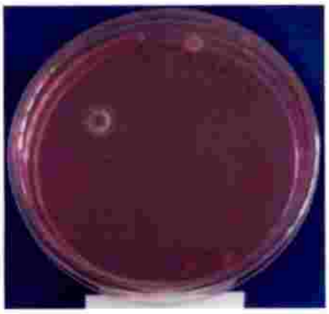
[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film
T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches
T_6: Rigid plastic boxes T_7: Glass containers]

Plate 7. Bacterial growth in intermediate moisture jackfruit after six months of storage in different packaging materials

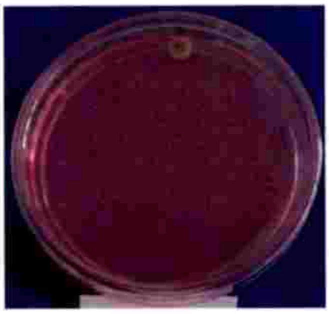
T1

T2

T3



T4



T5

T6

T7

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film
T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches
T_6: Rigid plastic boxes T_7: Glass containers]

Plate 8. Fungal growth in intermediate moisture jackfruit after six months of storage in different packaging materials

Table 26a. Effect of different packaging materials on mean sensory scores of IM jackfruit under ambient conditions, 2 months after storage

Samples	Appearance	Colour	Flavour	Texture	Odour	Taste	After taste	Overall acceptability	Total score
T_1*	3.20	2.60	3.40	3.80	4.20	4.60	4.80	4.40	31.00
T_2*	2.60	3.00	2.60	3.60	3.60	3.20	2.80	2.80	24.20
T_3*	3.20	3.00	3.40	3.60	3.80	3.20	2.80	2.60	25.60
T_4*	2.60	2.40	2.60	3.40	3.40	3.00	3.00	2.60	23.00
T_5*	3.20	3.40	3.40	3.60	4.80	4.80	3.40	3.60	30.20
T_6*	2.80	2.80	2.80	3.40	4.60	5.00	3.60	3.60	28.60
T_7*	2.80	3.00	3.00	3.80	4.80	4.80	4.20	4.00	30.40
Kendall's W test	0.13	0.12	0.16	0.055	0.44	0.35	0.28	0.43	

* Unmarketable after 2 months storage

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

Table 26 b. Effect of different packaging materials on mean sensory scores of IM jackfruit under refrigerated condition (2 months after storage)

Samples	Appearance	Colour	Flavour	Texture	Odour	Taste	After taste	Overall acceptability	Total score
T_1	8.00	7.60	7.80	7.00	6.60	7.60	6.60	7.80	59.00
T_2	7.20	6.60	7.00	6.40	6.00	6.80	5.80	5.80	51.60
T_3	5.80	5.80	6.40	6.20	5.60	6.00	5.40	5.60	46.80
T_4	5.40	5.20	4.40	5.00	4.80	4.20	3.60	3.60	36.20
T_5	5.60	4.80	5.00	5.20	4.60	4.60	4.00	4.60	38.40
T_6	5.80	5.00	4.60	5.00	5.00	5.20	4.40	4.00	39.00
T_7	7.00	6.40	6.40	6.00	6.00	6.60	6.00	6.60	51.00
Kendall's W test	0.666	0.508	0.638	0.594	0.484	0.598	0.567	0.787	

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

Table 26 c. Effect of different packaging materials on mean sensory scores of IM jackfruit under refrigerated condition (4 months after storage)

Samples	Appearance	Colour	Flavour	Texture	Odour	Taste	After taste	Overall acceptability	Total score
T_1	6.40	6.90	6.40	6.40	6.40	6.40	6.20	6.80	51.9
T_2	4.40	5.20	5.60	5.10	5.60	5.30	5.20	5.50	41.9
T_3	5.80	5.80	5.50	5.50	5.70	5.30	5.50	5.90	45.00
T_4	6.00	6.00	5.90	6.20	5.60	6.00	6.10	6.20	48.00
T_5	6.00	6.00	5.50	5.80	5.90	5.90	5.60	6.00	46.70
T_6	6.30	6.50	5.50	5.60	5.90	5.10	5.20	5.80	45.90
T_7	6.00	6.20	5.50	5.50	5.80	5.60	5.50	5.50	45.60
Kendall's W test	0.406	0.28	0.17	0.14	0.07	0.24	0.19	0.26	

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

Table 26 d. Effect of different packaging materials on mean sensory scores of IM jackfruit under refrigerated condition (6 months after storage)

Samples	Appearance	Colour	Flavour	Texture	Odour	Taste	After taste	Overall acceptability	Total score
T_1	5.30	5.80	5.40	5.10	5.10	6.10	5.10	5.60	43.50
T	3.50	4.10	4.50	4.20	4.50	6.30	4.20	4.30	35.60
T_3	4.60	4.30	4.30	4.20	4.90	6.40	4.50	4.40	37.60
T_4	5.00	4.70	4.90	5.20	4.70	6.50	4.70	4.60	40.30
T_5	5.90	6.00	4.90	5.60	5.40	6.30	5.50	6.40	46.00
T_6	5.30	5.20	4.70	4.70	4.50	6.00	4.40	4.70	39.50
T_7	5.80	5.40	5.40	5.10	4.90	6.00	4.70	4.50	41.80
Kendall's W test	0.67	0.51	0.64	0.59	0.48	0.60	0.57	0.79	

[T_1: LDPE 100 gauge T_2: LDPE 200 gauge T_3: Plastic trays over wrapped with cling film T_4: High impact polystyrene boxes (HIPS) T_5: Laminated aluminium foil pouches T_6: Rigid plastic boxes T_7: Glass containers]

DISCUSSION

Jackfruit is an indigenous crop and is commonly cultivated in Kerala. It is highly nutritious, possesses excellent processing attributes with good organoleptic characters and hence, it is highly suitable for value addition and processing. But it is under exploited due to its high perishability and bulky nature. Hence, proper postharvest technology for prolonging shelf life and processing methods for reducing postharvest losses are necessary. Intermediate moisture fruits (IMFs) are semi-dried fruits and vegetables with ideal water activity (a_w) between 0.65-0.90 and at this level of water activity, the texture of the product is soft, moist and more acceptable than conventionally dried fruits. Many under utilised tropical fruits with high nutritive value and health protective properties can be transformed into intermediate moisture fruits, which will enhance the market potential of these fruits. Jackfruit being an important fruit crop of Kerala, is an ideal choice for preparation of intermediate moisture fruit. Hence, the study on "Development, packaging and storage of intermediate moisture jackfruit (*Artocarpus heterophyllus* L.)" was carried out in the Department of Processing Technology, College of Horticulture, Vellanikkara during 2013-15. The discussion pertaining to the study is presented under the following heads.

5.1 Effect of pretreatments and dehydration temperature on quality of intermediate moisture jackfruit

5.2 Effect of packaging materials and storage temperature on quality of intermediate moisture jackfruit

5.1 Effect of pretreatments and dehydration temperature on quality of intermediate moisture jackfruit

Intermediate moisture jackfruit was prepared by subjecting the bulbs of jackfruit variety Muttam Varikka to additive infusion in a solution containing 60% sucrose, 0.2% ascorbic acid, 0.2% potassium metabisulphite and 2% matrix binding agent (calcium lactate/ sodium alginate/ corn starch/ cassava starch) for 12 hours, followed by drying at different dehydration temperatures (40±5, 50±5 and 60±5^{0}C) for 10-12 hours till an optimum moisture content was retained by the product. Quality of intermediate moisture jackfruit samples thus obtained was evaluated based on their acceptability through organoleptic evaluation and also in terms of their biochemical/nutritional constitution and microbial load.

5.1.1 Physical characteristics

5.1.1.1 Moisture (%)

The moisture content of intermediate moisture jackfruit ranged from 16.2 to 22.54 per cent. Moisture content of the product in all treatments decreased with increase in dehydration temperature. However, significant difference in moisture content was not observed among the treatments.

Panwar *et al*. (2013) reported a reduction in moisture content while preparing intermediate moisture aonla. They also reported a moisture content in the range of 20.0 to 31.3 per cent in intermediate moisture aonla. Sood (2000) also reported that intermediate moisture papaya cubes have moisture content between 25.44 and 35.67 per cent.

5.1.1.2. Water activity

A declining trend in water activity was observed with increase in dehydration temperature in all the treatments. Jackfruit bulbs without any pretreatment (control) showed higher water activity at all dehydration temperatures. Control samples dehydrated at 40±5^{0}C showed the highest water activity (0.80) wheras the lowest (0.76) was seen in intermediate moisture jackfruit dehydrated at 60±5^{0}C.

Ayub and Alam (2002) also reported that water activity decreased in intermediate moisture apple slices after osmotic and cabinet dehydration. Osmotically dehydrated apples showed a decline in water activity during 0, 30, 60 and 90 minutes of dehydration (Simpson *et al*. 2010). Panwar (2010) reported a water activity of 0.71 to 0.77 in intermediate moisture aonla.

5.1.1.3 Drying rate

Rate of drying was faster at higher dehydration temperature in all the treatment combinations. Dehydration at 60±5^{0}C showed a steady decline throughout the process whereas at 40±5 and 50±5^{0}C, a steep decline was observed during the initial four hours, followed by a gradual decline afterwards. Dehydration at 40 ± 5^{0}C took 12 hours to reach the appropriate moisture content whereas it took 10 hours to dehydrate the product at 50 ± 5 and 60 ± 5^{0}C. Reduction in dehydration time at higher temperatures may be due to accelerated rates of moisture loss.

Kaushal and Sharma (2014) reported that the drying rate of jackfruit was faster at the beginning and then became slower. Reduction in the available moisture and the development of case hardening may be the reason for the reduction in drying rate. One of the reasons for reduction in drying rate is development of shrinkage which causes reduction in porosity of the jackfruit samples with advancement of the drying process.

Aggarwal and Kaur (2014) also reported that intermediate moisture carrot pulp showed a loss in weight with drying time and during dehydration, weight loss was rapid in the first hour of drying followed by slow decrease in weight in the subsequent hours.

5.1.1.4. Colour values

Intermediate moisture jackfruit showed colour ranging from vivid yellow to brilliant yellow. There was not much difference in colour intensity among the treatments. When the dehydration temperature increased, a slight increase in colour intensity was observed.

Kaushal and Sharma (2014) reported that colour of jackfruit samples was affected by increase in dehydration temperature. The jackfruit samples dried at 60^{0}C were found better as compared to samples dried at 50 and 70^{0}C in terms of b value. The samples, dehydrated at 60^{0}C were rated better as far as drying and colour characteristics of jackfruit samples were concerned.

5.1.2 Biochemical characteristics

5.1.2.1 Total Soluble Solids (^{0}Brix)

Addition of sucrose in combination with other food additives, followed by dehydration increased TSS of intermediate moisture jackfruit. TSS content of the product in all treatments increased with increase in dehydration temperature and among the treatment combinations, maximum TSS (67.67^{0}Brix) was recorded in intermediate moisture jackfruit containing corn starch as binding agent. Higher TSS in intermediate moisture jackfruit subjected to additive infusion as compared to control samples may be due to solute impregnation in the bulbs during steeping.

Mariane *et al*. (2011) reported that after osmotic dehydration and subsequent drying, TSS content of jackfruit was 61 ± 1° Brix. A TSS content of 54 per cent was reported in intermediate moisture carrot preserve (Sethi and Anand., 1982). Ramanuja and Jayaraman(1980) also reported 65 per cent TSS in the intermediate moisture banana.

5.1.2.2 Titratable acidity(%)

Immersion of jackfruit bulbs in osmotic solution, followed by dehydration resulted in a decrease in acidity of the product. Increase in dehydration temperature increased the titratable acidity of all samples. Control samples had higher titratable acidity than the bulbs subjected to additive infusion before dehydration. The lower titratable acidity in the samples subjected to additive infusion may be due to their higher TSS, of which sucrose is a major ingredient.

The titratable acidity of dehydrated jackfruit bulb decreased as the concentration of sugar solution increased and it was maximum at 60°C tray drying (Swami *et al*., 2014).

Sood (2000) reported that the acidity value of control sample in intermediate moisture papaya was 0.297 per cent, while in samples treated with glycerol and sorbitol supplemented with sugars, it was 0.265.

5.1.2.3. Total ash (%)

Higher ash content was retained by the control samples at all dehydration temperatures. Jackfruit bulbs without any pretreatments (control) dehydrated at 60±5^{0}C, retained maximum ash content (3.63%) and the minimum (1.50%) in the samples treated with corn starch and dehydrated at 60 ± 5^{0}C. Higher ash content in the control samples may be due to the high dry matter in them which remained intact as they were not subjected to leaching during immersion in osmotic solution.

Sood (2000) reported that the ash content of intermediate moisture papaya varied from 0.72 to 1.80 per cent and control sample showed a higher value of ash content of 1.68 per cent.

5.1.2.4. pH

The pH of intermediate moisture jackfruit was in the range of 5.48 to 6.35. pH of the product showed a decreasing trend with increase in dehydration temperature. Samples dehydrated at 40 ± 5^{0}C had higher pH as compared to those dehydrated at 50 ± 5 and 60 ± 5^{0}C. Intermediate moisture jackfruit containing cassava starch followed by dehydration at 40 ± 5^{0}C, had the highest pH (6.35) and the lowest (5.48) in the control sample dehydrated at 60 ± 5^{0}C. Solute impregnation of the bulbs before dehydration may have increased the pH in the bulbs subjected to additive infusion as compared to the control samples.

Mariana *et al*., (2011) reported that the pH of fresh jackfruit bulbs was 5.7 and that of the dried ones was 5.1.

5.1.2.5. Sugars (%)

Reducing, non-reducing and total sugars of intermediate moisture jackfruit increased with increase in dehydration temperature. The reducing, non-reducing and total sugars were in the range of 7.86 to 16.92, 18.29 to 43.59 and 26.16 to 58.76 respectively. Jackfruit bulbs subjected to additive infusion retained higher sugar content as compared to the control samples. Additive infusion of bulbs may have increased the sugar content of intermediate moisture jackfruit and subsequent dehydration may have resulted in concentration of sugars in the product.

Swami *et al*., (2014) reported that non-reducing and total sugars in dehydrated jackfruit increased as the osmotic concentration increased.

The reducing sugar contents in jackfruit types studied, exhibited a range from 8.63 per cent to 14.6 per cent (Jagadeesh *et al*., 2007).

The total sugar content of intermediate moisture apricot ranged from 40.03 to 54.56 (Sharma *et al*., 2006).

5.1.2.6. Ascorbic acid (mg/100g)

Ascorbic acid content of intermediate moisture jackfruit subjected to pretreatments before dehydration was significantly higher as compared to the control samples. Reduction in ascorbic acid content was higher with increase in dehydration temperature. Higher ascorbic acid content in intermediate moisture jackfruit bulbs subjected to pretreatments was due to the incorporation of ascorbic acid during additive infusion, as compared to the control samples. Higher losses in ascorbic acid content of intermediate moisture jackfruit with increase in dehydration temperature may be due to the heat labile property of this vitamin. During dehydration ascorbic acid will get converted to dehydro ascorbic acid.

Vitamin C content in jackfruit was found to be 12 to 14 mg per 100 g (Narasimham, 1990).

Ayub *et al*. (2005) found that ascorbic acid content decreased from 293.9 to 44.51 mg/100 g during dehydration in IM guava slices.

5.1.2.7. Total carotenoids (mg/100 g)

Increase in dehydration temperature decreased the total carotenoid content of the product. Total carotenoid content was the highest (2.85 mg/100 g) in intermediate moisture jackfruit containing corn starch and dehydrated at 40 ± 5^0C, while the lowest (1.94 mg/100 g) was observed in the control sample dehydrated at

60 ± 5^{0}C. Higher losses in carotenoid content of intermediate moisture jackfruit during dehydration at higher temperatures may be due to the heat labile property of these pigments, which are also sensitive to oxidation.

Saxena *et al.*, (2012) reported that carotenoid is highly susceptible to oxidation reaction, which is accelerated at higher temperature. He reported 50 per cent reduction in the total carotenoid content of fresh jackfruit bulbs after 5 hours of dehydration at 50^{0}C.

5.1.2.8. Total flavanoids (mg/100 g)

Decline in the levels of total flavanoids of intermediate moisture jackfruit was seen with increase in dehydration temperature. Highest flavanoid content (21.33 mg/100 g) was observed in the product containing corn starch and dehydrated at 40 ± 5^{0}C, and the lowest (11.0 mg/100 g) in the control samples dehydrated at 60 ± 5^{0}C. Higher temperature may have accelerated the decline in flavanoid content of intermediate moisture jackfruit during dehydration

During storage of minimally processed jackfruit bulb, total phenolics were reported to an extent of 45 mg/100 g and flavanoids to an extent of 23 mg/100 g at the initial storage stage (Saxena *et al.*, 2009a).

5.1.2.9 Microbial observation (cfu/g)

Bacterial and fungal population was negligible and within the prescribed limits in intermediate moisture jackfruit and it decreased with increase in dehydration temperature. Jackfruit bulbs without any pre-treatment (control) had higher fungal load at all dehydration temperatures. Jackfruit bulbs without any pre-treatments (control) and dehydrated at 40 ± 5^{0}C had highest fungal load (4 x 10^3 cfu/g) while those containing corn starch, followed by dehydration at 50 ± 5 and 60 ± 5^{0}C. Intermediate moisture jackfruit containing cassava starch when dehydrated at 60 ± 5^{0}C was devoid of fungus.

Bacterial population in control samples was higher as compared to the ones subjected to pretreatments. Higher dehydration temperature resulted in lower population.

Subjecting jackfruit bulbs to pretreatments containing the antimicrobial compound potassium metabisulphite may have hindered microbial proliferation. Higher dehydration temperatures leading to reducing moisture content may have retarded bacterial proliferation in the product.

None of the samples tested positive for *Escherichia coli.*

An initial reduction in total bacterial count was observed in corn zein coated intermediate moisture apricots (Baysal, 2010).

4.1.2.10. Organoleptic evaluation

Intermediate moisture jackfruit containing corn starch as the matrix binding agent in addition to food additives like sucrose (60%), ascorbic acid (0.2%) and potassium metabisulphite (0.2%) was significantly superior in organoleptic properties at all dehydration temperatures. Intermediate moisture jackfruit treated with these food additives and subjected to dehydration at 60 ± 5^0C, had maximum score in terms of colour, flavour, texture and overall acceptability. Jackfruit bulbs without any pre-treatments (control) had minimum score for organoleptic properties at all dehydration temperatures.

Subjecting jackfruit bulbs to additive infusion involving a combination treatment of 2 per cent corn starch, 60 per cent sucrose, 0.2 per cent ascorbic acid and 0.2 per cent potassium metabisulphite, followed by dehydration (60 ± 5^0C) may have enhanced the organoleptic attributes of intermediate moisture jackfruit. Solute impregnation may have resulted in improved flavour, better colour and altered palatability as compared to control samples.

Intermediate moisture apple slices prepared by using sucrose: glucose in the ratio 7:3, potassium metabisulphite and ascorbic acid retained best color, texture

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and also obtained maximum mean score (6.8) for overall acceptability (Akhtar and Javed, 2013).

Osmodehydration of jackfruit followed by drying using convective hot air at 60°C for 6 h resulted in a product with higher solids content, lower moisture content and good sensory characteristics (Mariane *et al.*, 2011).

Intermediate moisture aonla segments developed using 60 per cent sucrose showed highest sensory score in colour, appearance, taste, mouthfeel, texture and overall acceptability (Panwar, 2010).

5.2 Effect of packaging materials and storage temperature on quality of intermediate moisture jackfruit

Statistical analysis of the quality parameters of intermediate moisture jackfruit developed through various treatment combinations revealed significant difference with respect to only vitamin C and pH. Therefore, the best one among the five treatments was selected based on microbial quality and organoleptic properties. Dehydration temperature for the production of intermediate moisture jackfruit at 60 ± 5^0C resulted in minimum microbial load in the product with respect to bacteria and fungi. *E.coli* was not detected in any of the samples. With respect to organoleptic properties, intermediate moisture jackfruit containing corn starch (2%) as the matrix binding agent had maximum score for colour, flavour, texture and overall acceptability at all dehydration temperatures. Therefore, jackfruit bulbs treated with corn starch (2%), sucrose (60%), ascorbic acid (0.2%) and potassium metabisulphite (0.2%) followed by dehydration at 60 ± 5^0C was selected as the best treatment combination for the development of intermediate moisture jackfruit with the intention of having minimum microbial load and maximum organoleptic acceptability.

The product thus developed was packed in seven different types of packaging material and was stored at two different levels of temperature (ambient and refrigeration). Observations were recorded at an interval of two months during storage. The packaging materials used for storage studies are as follows:

T_1: Low density polyethylene pouches (LDPE 100 gauge)

T_2: Low density polyethylene pouches (LDPE 200 gauge)

T_3: Plastic trays over wrapped with cling film

T_4: High impact polystyrene boxes (HIPS)

T_5: Laminated aluminium foil pouches

T_6: Rigid plastic boxes

T_7: Glass containers

5.2.1 Physical characteristics

5.2.1.1. Moisture(%)

Moisture content of intermediate moisture jackfruit showed a declining trend throughout the storage period. Intermediate moisture jackfruit stored under refrigerated condition had higher moisture content in all the packaging materials. Samples stored in glass jar under refrigerated condition retained maximum moisture (13.67%) and the minimum (9.50%) in LDPE (100 gauge) bags, after a period of six months.

Loss of moisture in intermediate moisture fruits occur chiefly due to evaporation of moisture from the product. Higher moisture content in intermediate moisture jackfruit stored in glass container may be due to better barrier properties imparted by low rates of water vapour transmission.

Hussain *et al*. (2004) reported decreasing trend in moisture content of osmotically dehydrated banana slices during storage intervals. Pattanapa *et al.* (2010) also reported similar results in osmotically dehydrated mandarin. The moisture content of intermediate moisture apricot decreased with storage time

(Baysal *et al*., 2010). According to Panwar (2010), a significant decrease in moisture content of both sweet and spiced intermediate moisture aonla segments was observed during six months storage.

5.2.1.2 Water activity

Water activity decreased during storage period. Decline of water activity was more under ambient conditions and less under refrigerated condition. Intermediate moisture jackfruit stored in glass containers retained maximum water activity throughout storage.

Higher water activity retention in intermediate moisture jackfruit stored in glass container may be due to higher moisture content in the samples. Decline in water activity was not significant during storage and was higher under ambient conditions. This may be due to lower rates of biochemical reactions and better retention of physical properties when stored at low temperature in packaged condition.

Intermediate moisture carrot pulp showed a decreasing trend in water activity at higher room temperature than at refrigeration temperature (Agarwal and Kaur, 2014). Relationship between water activity and stability of food was studied by Karel (1978) and found that each food had an optimum water activity at which it gave relatively increased storage life. Beyond that limit the rate of deterioration increased and thus reduced the storage life. A decrease in water activity of persimmon slices during storage was reported by Ayub (2003). Panwar (2010) observed a significant decrease in water activity values of intermediate moisture aonla during six months storage.

5.2.1.3 Equilibrium Relative Humidity

Intermediate moisture jackfruit was at equilibrium at a relative humidity of 64.3 per cent. Variation in colour was noticed beyond this level of relative humidity. Fungal growth was observed at a relative humidity of 75.8 per cent and above. The optimum relative humidity for intermediate moisture jackfruit was found to be below 64.3 per cent for safe storage and better shelf life.

The critical moisture point during storage of osmo-air dehydrated apricot was at 60 per cent relative humidity with 12.5 per cent equilibrium moisture content whereas, the optimum equilibrium relative humidity was found to be 48 per cent at 25^{0}C. Dried apricot samples at and above 80 per cent relative humidity became succeptible to moulds (Sharma *et al*., 2000)

5.1.1.4 Critical Moisture Point

Critical moisture point of intermediate moisture jackfruit was found to be 16.83 per cent. The quality of most dried foods depends on their physical, chemical and microbiological stability to a great extent. This stability is a consequence of the relationship between the EMC of the food material, and its corresponding water activity, at a given temperature (Myhara *et al*., 1998).

As the moisture content is reduced to such a low level compared to most agricultural products, equilibrium moisture content (EMC) plays an important role at the end of drying (Temple and Van Boxtel, 1999).

5.1.1.5 Colour variation

Intermediate moisture jackfruit stored under refrigerated condition showed minimum in its colour throughout the storage period. Intemediate moisture jackfruit packed in LDPE (100 and 200 gauge), laminated aluminium foil pouches and glass jars showed maximum retention of colour during storage period. Samples stored under ambient conditions showed maximum variation after two months of storage. Samples packed in plastic trays overwrapped with cling film showed less retention of colour than other treatments during storage. Samples packed in plastic trays overwrapped with cling film, rigid plastic boxes and high impact polystyrene boxes showed darkening at the end of storage period.

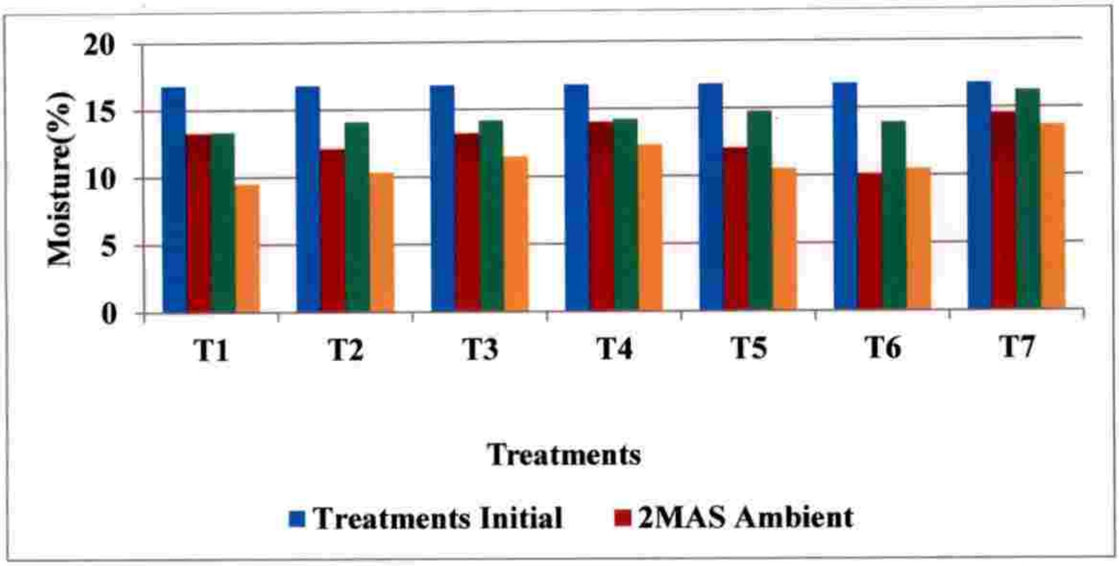

Fig 5. Effect of packaging materials on moisture content (%) of intermediate moisture jackfruit during storage

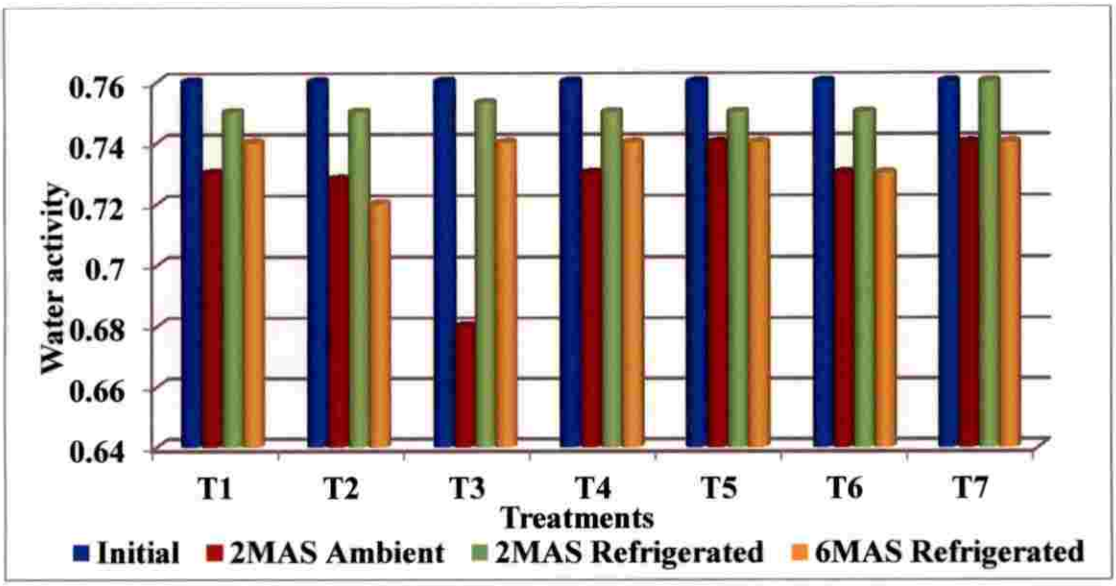

Fig 6. Effect of packaging materials on water activity of intermediate moisture jackfruit during storage

5.2.2 Biochemical characteristics

5.2.2.1 Total Soluble Solids (^{0}Brix)

TSS showed an increasing trend during storage, irrespective of the packaging material. Samples stored under ambient conditions had higher TSS as compared to the refrigerated ones. Glass containers retained maximum TSS as compared to other packaging materials. TSS content of samples packed in glass container was 73.13^0 Brix after two months of storage, which increased to 78.9^0 Brix, after six months of storage, under refrigerated conditions.

Rani and Bhatia (1986) reported a gradual increase in TSS of pear candy during storage.

The total soluble solids in intermediate moisture aonla segments increased significantly during six months of storage and ranged between 32.0 to 48.9 per cent (Panwar, 2010).

5.2.2.2 Titratable acidity (%)

An increasing trend in titratable acidity was noticed in intermediate moisture jackfruit during storage in all the packaging materials, irrespective of storage condition. Titratable acidity was higher under ambient conditions as compared to refrigerated storage. Increase in titratable acidity may be due to loss of moisture from the product. Higher acidity in samples packed in cling film overwrapped trays may be due to higher moisture loss in these packaging materials.

Acidity values of intermediate moisture aonla preserve increased gradually with the storage duration (Sethi, 1980). Akthar and Javed (2013) also observed that acidity increased during two months of storage period in intermediate moisture apple slices. According to Panwar (2010), titratable acidity of intermediate moisture aonla increased significantly with increase in storage period upto six months.

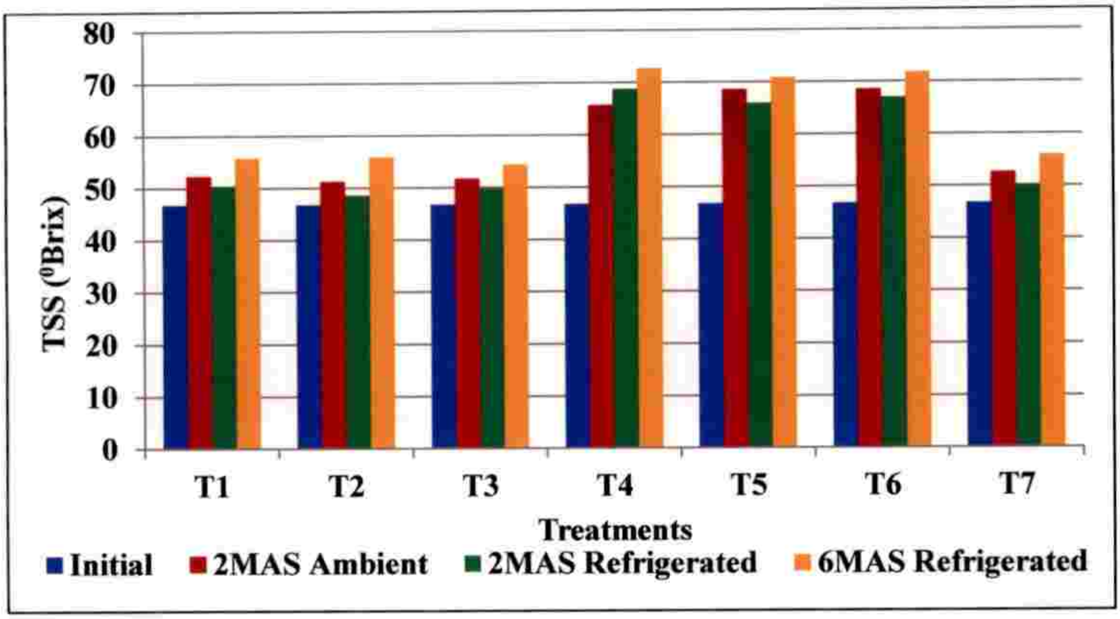

Fig 7. Effect of packaging materials on TSS (^{0}Brix) of intermediate moisture jackfruit during storage

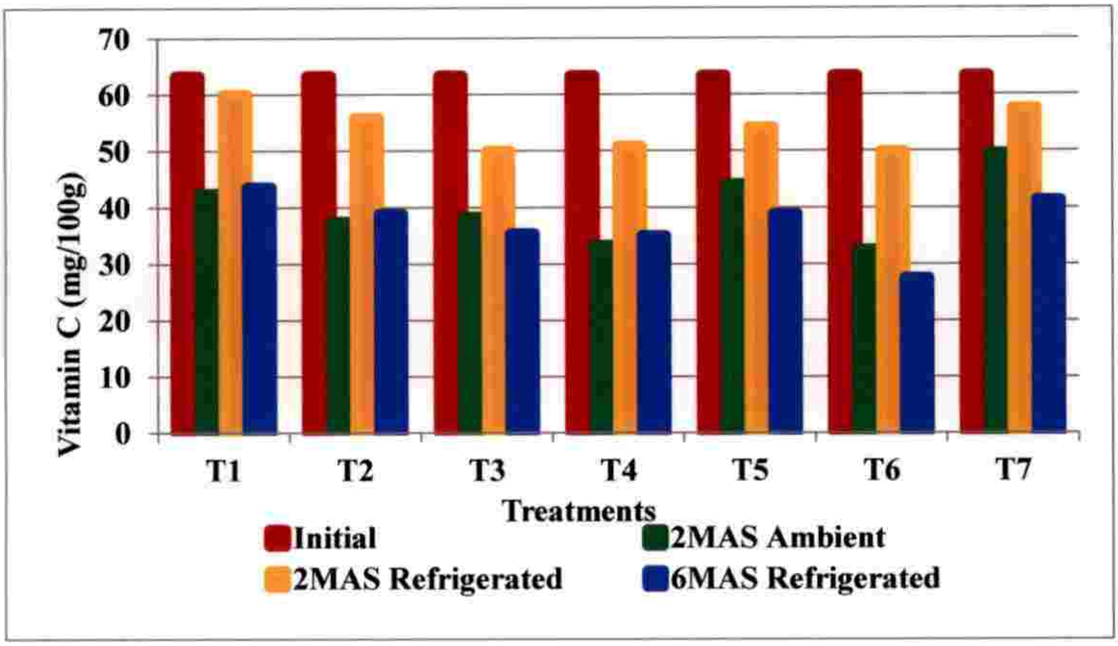

Fig 8. Effect of packaging materials on ascorbic acid content (mg/100g) of intermediate moisture jackfruit during storage

5.2.2.3. Ash content (%)

Ash content increased with increase in storage period. The increase in ash content was more under ambient conditons as compared to the samples stored under refrigerated condition. After six months of storage period, intermediate moisture jackfruit packed in glass container retained the highest ash content (2.57%) and the lowest in the samples packed in HIPS boxes (2.27%).

The ash content of intermediate moisture apple slices showed an increase from 99.76 per cent to 99.95 per cent during two months of storage period (Akthar and Javed, 2013).

5.2.2.4. pH

pH of all samples decreased during storage. The decrease in pH was more under ambient conditions than under refrigerated storage. After two months of storage, intermediate moisture jackfruit packed in glass jars and stored under refrigerated condition showed minimum variation in pH (6.66 to 6.64) and the samples packed in rigid plastic box and stored under ambient conditions showed maximum variation (6.66 to 6.02).

Samples packed in glass containers showed the least variation in pH, after six months of storage. The decrease in pH may be due to increase in titratable acidity, reducing and total sugars.

The pH of intermediate moisture apple slices was 4.08, which decreased to 3.90 during two months of storage period (Akthar and Javed, 2013). A decrease was observed in pH of semi-concentrates prepared from orange, pineapple and tomatoes during storage, when packed in aluminium foil laminates (Das and Jayaraman, 1995).

5.2.2.5 Sugars (%)

Reducing and total sugars of intermediate moisture jackfruit increased while non reducing sugars decreased in all the packaging materials under both ambient and refrigerated conditions. Rise in reducing and total sugars was more under ambient conditions and samples packed in glass containers showed the least variation in reducing and total sugars. Higher levels of reducing and total sugars under ambient conditions may be due to accelerated rates of biochemical reactions at ambient temperature, which resulted in increased hydrolysis of complex sugars. Least variation in reducing and total sugars in the samples stored in glass containers may be due to better insulating properties of glass to external agencies of deterioration.

A fall in non reducing sugars was noticed in all the samples and the decline was less under refrigerated condition. Decline in non reducing sugars may be due to conversion of non reducing sugars into reducing sugars during storage and the rate of conversion was slower under refrigerated condition.

Sethi (1980) reported that reducing sugars showed an increasing trend and total sugars showed a decreasing trend in intermediate moisture aonla preserve during storage. An increase in sugar content was observed during the storage of intermediate moisture carrot preserve (Sethi and Anand, 1982). During the storage of sand pear candy, an increasing trend was observed in the content of reducing sugars (Rani and Bhatia, 1985; 1986). Different cultivars of aonla candy showed a decrease in reducing sugar and an increase in total sugars during 9 months of storage (Nayak *et al*., 2012). Priya and Khatkar (2013) found that total and reducing sugars in aonla preserve increased during storage period. A significant increase in total sugars of sweet and spiced intermediate moisture aonla segments was observed with the increase in storage period upto six months (Panwar, 2010). Reducing sugars of intermediate moisture aonla segments showed an increase from 10.6 to 12.5g/100g during six month of storage period (Panwar, 2010).

5.2.2.6 Ascorbic acid (mg 100 g^{-1})

Ascorbic acid content of all samples decreased throughout the storage period. Significantly higher ascorbic acid was retained by the samples held under refrigerated condition as compared to the ones stored under ambient conditions.

Ascorbic acid is sensitive to oxidation and higher temperature conditions under which it gets converted to dehydro ascorbic acid. The rate of reaction proceeds faster at higher temperatures.

A decrease in ascorbic acid content of osmotically dehydrated banana slices was noticed during storage (Hussain *et al*., 2004). Ascorbic acid content decreased with the increase in storage duration in aonla candy (Singh *et al*., 2008). Ascorbic acid in intermediate aonla segments decreased significantly during six months of storage (Panwar, 2010). A remarkable reduction was noted in ascorbic acid (vitamin C) content of osmodehydrated jackfruit during storage (Rahman *et al*., 2014).

5.2.2.7 Total carotenoids (mg 100 g^{-1})

Total carotenoid content of intermediate moisture jackfruit showed a declining trend during storage. Decline was more under ambient conditions as compared to refrigerated conditions. Samples packed in glass containers retained maximum carotenoids. Better retention of carotenoids under refrigerated condition may be due to the lower temperature and lesser oxidation, as these factors are chiefly responsible for carotenoid degradation. Higher retention of carotenoids by glass container may be due to better barrier properties of glass to light and temperature.

Mehta and Tomar (1980) reported that 50 per cent of carotenoids was retained in dehydrated papaya after twelve months of storage. A remarkable reduction was noted in β-carotene (53.02 μgm/gm) content of osmodehydrated jackfruit during storage (Rahman *et al*., 2014).

5.2.2.8 Total flavanoids

Flavanoids in intermediate moisture jackfruit fell throughout the storage period. The fall in flavanoid content was more under ambient conditions than under refrigerated storage. Significant difference in flavanoid content was not observed with respect to the combined effect of packaging material and storage temperature.

Higher retention of flavanoids under refrigerated condition may be due to slower rates of bio chemical reactions at low temperature.

Minimally processed jackfruit bulbs stored under modified atmospheric conditions showed a decrease in flavanoid content during storage. Stabilization of the bulbs with chemical additives and the synergestic effect of MA conditions reduced the loss in phenolics and flavanoids during storage (Sally *et al.,* 2011).

5.2.2.9 Non enzymatic browning (Absorbance)

Non enzymatic browning increased throughout the storage period. All samples stored under refrigerated condition, irrespective of the packaging material showed significantly lower non enzymatic browning as compared to the ones kept under ambient conditions. Increase in the levels of reducing and total sugars along with organic acids and their resultant interaction may have led to increased browning in the product during storage. Higher non enzymatic browning values in samples stored under ambient conditions may be due to faster rates of bio chemical reactions at higher temperature.

Browning reactions increase to a maximum in the range of intermediate moisture foods and are usually slow at low humidity and at a range beyond that of intermediate moisture foods. Browning, which results from the enzymatic and non enzymatic reactions is a major concern during drying of fruits (Kiranoudis *et al.*, 1992). In jackfruit, the effect of non enzymatic browning was found to be more pronounced at 70^0C, after 10 hours of drying. NEB increased upto 122 per cent from the initial value at 70^0C, whereas it was almost half from initial at 50^0C, after same duration of drying (Saxena *et al.*, 2012). A gradual increase in non enzymatic browning of intermediate moisture aonla preserve was observed by Sethi (1980) with increasing period of storage at ambient temperature. Non enzymatic browning showed a significant increase in intermediate moisture aonla segments with progressive increase in storage period (Panwar, 2010).

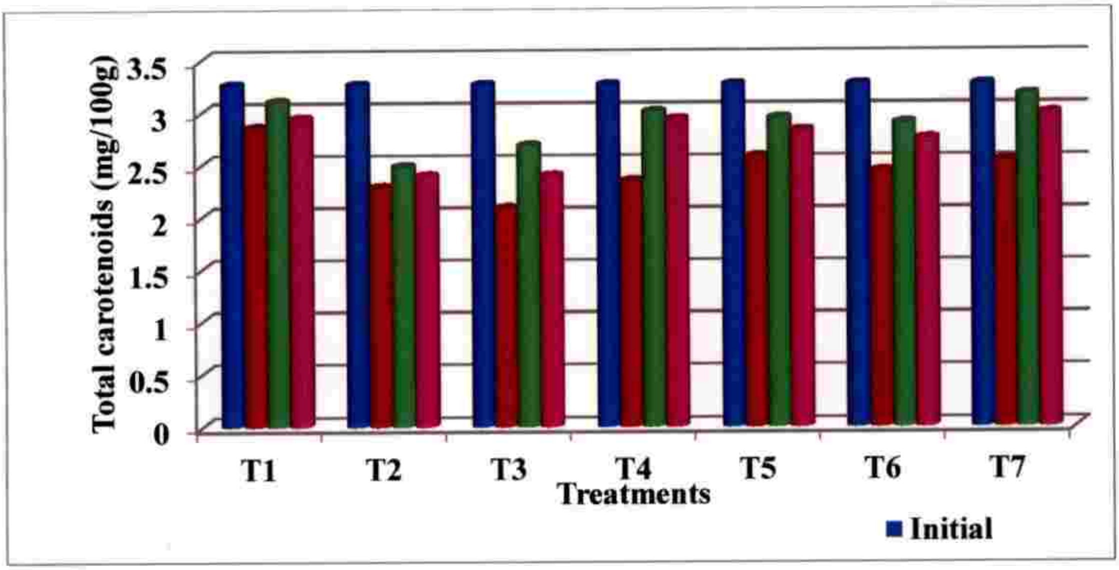

Fig 9. Effect of packaging materials on total carotenoids (mg/100 g) of intermediate moisture jackfruit during storage

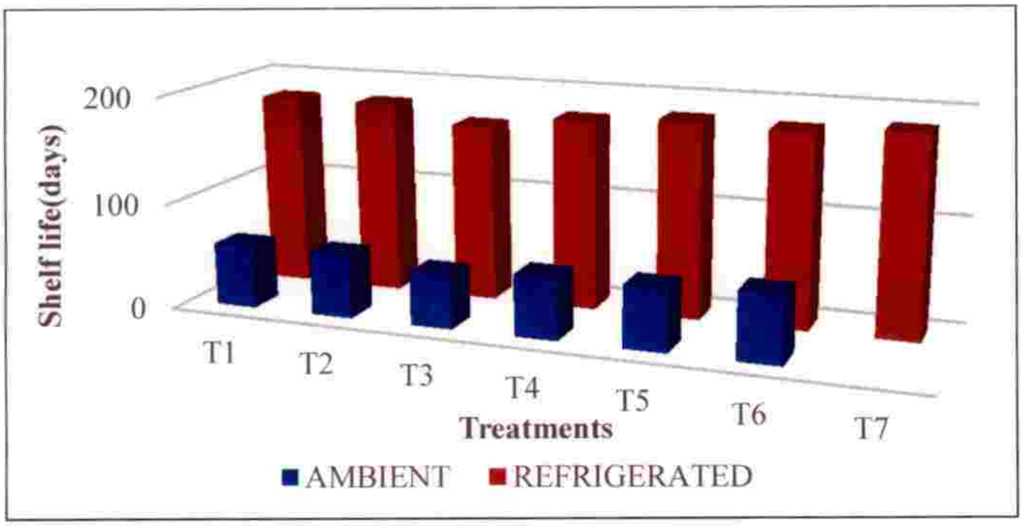

Fig 10. Effect of packaging materials on shelf life (days) of intermediate moisture jackfruit during storage

5.2.2.10 Shelf life

Intermediate moisture jackfruit stored under ambient conditions had a shorter shelf life when compared to that stored under refrigerated condition. All the treatments kept at ambient temperature became unmarketable within two months of storage. Treatments showed browning after one month of storage and were completely discarded after 75 days. Intermediate moisture jackfruit stored in plastic tray overwrapped with cling film showed minimum shelf life (50 days) while that stored in glass container showed maximum shelf life (62.33 days) under ambient conditions. Intermediate moisture jackfruit stored under refrigerated condition in HIPS, LDPE 100 gauge and glass container had more shelf life than other treatments. They were marketable upto 7 months.

Intermediate moisture aonla prepared using osmotic agents like sucrose and glycerol showed a shelf life of six months (Panwar *et al*., 2013). The shelf life of the intermediate moisture carrot increased from three to six months at ambient temperature, when dried using infrared drier and at radiation dose of 0.5 kGy (Chaturvedi *et al*., 2013).

5.2.2.11 Microbial population (cfu/g)

Bacterial and fungal population were within the permissible levels throughout the storage period. Significant increase in bacterial and fungal populations was not seen with respect to the packaging material and storage temperature. However, population of bacteria and fungus were more under ambient conditions. Presence of *Escherichia coli* was ruled out throughout the storage period. Higher microbial population under ambient conditions may be due to the congenial atmospheric conditions for microbial growth at warmer temperature as compared to refrigerated storage.

Jayaraman *et al.* (1974) observed that the intermediate moisture guava prepared by immersion equilibration procedure using a soak solution containing glycerol, sucrose, water and potassium sorbate was resistant to bacterial, yeast and mould growth and was microbiologically sound for consumption upto three months at 37^{0}C. Jayaraman *et al.* (1975) again revealed that the total plate count in intermediate moisture pineapple chunks decreased to negligible level during storage upto 9 months. Ramanuja and Jayaraman (1980) reported that plate count was negligible (100 colonies/g) in intermediate moisture banana and the storage stability was up to 9 months at room temperature. Sethi and Anand (1982) stated that intermediate moisture carrot preserve could remain microbiologically sound upto six months. Intermediate moisture pear showed least yeast and mould count initially and upto 90 days of storage (Barmanray, 1998). Microbial load of intermediate moisture apricots coated with corn zein increased after 4 months of storage at 5 and 20^{0}C (Baysal, 2010). No coliforms were observed with respect to EMB agar medium in all minimally processed jackfruit samples during the entire storage period (Sally *et al.*, 2011).

5.2.2.12 Organoleptic evaluation

Sensory score of all treatments showed a declining trend throughout the storage period. Decline in sensory score was more for treatments stored under ambient condition than that stored under refrigerated condition. Intermediate moisture jackfruit packed in LDPE (100 gauge) had the highest organoleptic score upto four months of storage, followed by the samples in glass container. After six months of storage period, samples stored in laminated aluminium foil pouches showed the highest total score and that stored in LDPE (200 gauge) showed the least total score.

Jayaraman *et al.* (1974) found that intermediate moisture guava samples showed slight browning and weakening of flavour beyond 4 months but it was organoleptically acceptable upto 6 months. Similar observations were made by the same group one year later in case of intermediate moisture pineapple chunks (Jayaraman *et al.*, 1975). Pear jam and intermediate moisture pear showed a decrease in organoleptic quality with storage (Rani and Bhatia, 1986). The overall acceptability was significantly higher in intermediate moisture apricot prepared using 70 per cent sugar syrup and it decreased as the storage period advanced (Sharma *et al*., 2006). Intermediate moisture pineapple slices had good texture, colour and sensory acceptability upto 40 days of storage (Saxena *et al*., 2009). Panwar (2010) reported that intermediate moisture aonla segments showed a significant decrease in mean score for colour, texture, taste, appearance and mouth feel during storage and it remained acceptable upto three months with respect to colour, appearance, taste and mouth feel. During six months of storage, the overall acceptability of sweet intermediate moisture aonla segments decreased significantly from 8.0 to 4.4 (Panwar *et al*., 2013).

SUMMARY

The main objectives of the study were to develop intermediate moisture jackfruit by subjecting the bulbs to various pretreatments followed by dehydration and to evaluate the quality of the product thus developed by packaging it in different types of packaging materials and subsequent storage under ambient and refrigerated conditions.

Intermediate moisture jackfruit was prepared by subjecting the bulbs of jackfruit variety Muttam Varikka to additive infusion in a solution containing 60% sucrose, 0.2% ascorbic acid, 0.2% potassium metabisulphite and 2% matrix binding agent (calcium lactate/sodium alginate/corn starch/cassava starch) for 12 h, followed by drying at different dehydration temperatures (40 ± 5, 50 ± 5 and 60 ± 5^0C) for 10-12 h till an optimum moisture content was retained by the product. Quality of intermediate moisture jackfruit samples thus obtained was evaluated based on their acceptability through organoleptic evaluation and also in terms of their biochemical/nutritional constitution and microbial load.

The moisture content of intermediate moisture jackfruit ranged from 16.2 to 22.54 per cent and the water activity of the product was in the range of 0.76 to 0.80. Rate of drying was faster with increase in dehydration temperature in all the treatment combinations. Rapid loss in moisture was faster during the initial four hours and after that it showed a gradual decline. Dehydration at 60 ± 5^0C showed a steady decline throughout the process whereas at 40 ± 5 and 50 ± 5^0C, a steep decline was observed during the initial four hours, followed by a gradual decline afterwards.

Addition of sucrose in combination with other food additives, followed by dehydration resulted in an increase in the TSS content of intermediate moisture jackfruit, which showed a maximum value of 67.67^0Brix. Jackfruit bulbs when subjected to additive infusion followed by dehydration, resulted in an increase in TSS, total, reducing and non reducing sugars whereas carotenoids and flavanoids

Intermediate moisture jackfruit stored under ambient conditions had a shelf life of two months, whereas the samples stored under refrigerated condition had a shelf life of six months.

Intermediate moisture jackfruit packed in glass containers showed maximum retention of moisture (13.67%), water activity (0.74), acidity (0.34%), reducing sugars (24.91), total sugars (61.41%) and total carotenoids (2.98mg/100g), after six months of storage. The water activity of samples packed in LDPE (100 gauge) bags was on par with the ones stored in glass container while it retained maximum ascorbic acid (43.66 mg), after a storage period of six months. Non enzymatic browning increased throughout the storage period.

Organoleptic properties of intermediate moisture jackfruit showed a declining trend during storage. Intermediate moisture jackfruit packed in LDPE (100 gauge) had the highest organoleptic score upto four months of storage, followed by the samples in glass container. But after six months of storage period, samples packed in laminated aluminium foil pouches showed highest organoleptic score.

Subjecting jackfruit bulbs to additive infusion followed by dehydration resulted in intermediate moisture jackfruit with an optimum moisture content, which imparted a soft texture, improved flavour and colour to the product. Quality of the packaged product could be maintained upto two months under ambient conditions. Under refrigerated conditions, it could be stored for six months with minimum conspicous changes. Packaging was highly beneficial to maintain product characteristics during storage under ambient and refrigerated conditions.

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APPENDIX- I

Score card for organoleptic evaluation of intermediate moisture jackfruit

Name of the judge:

Date:

Characteristics	Score				
	T_1	T_2	T_3	T_4	T_5
Appearance					
Colour					
Flavour					
Texture					
Odour					
Taste					
After taste					
Overall acceptability					

9 point Hedonic scale

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

Signature:

APPENDIX II

MEDIA COMPOSITION

1. NUTRIENT AGAR MEDIA (FOR BACTERIA)

Beef extract	: 3 g
Peptone	: 5 g
Sodium chloride	: 5 g
Agar	: 18 g
Distilled water	: 1000 ml
pH	: 6.8-7.2

2. POTATO DEXTROSE AGAR MEDIA (FOR FUNGUS)

Peeled potatoes	: 250 g
Dextrose	: 20 g
Agar	: 18 g
Distilled water	: 1000 ml
pH	: 5.6

3. EOSIN METHYLENE BLUE AGAR (FOR *E.coli*)

Pepton	: 10g
Dipotassium phosphate	: 2g
Lactose	: 10g
Eosin – Y	: 0.4g
Methylene blue	: 0.065g
Agar	: 15g
Distilled water	: 1 L
pH	: 7.1

APPENDIX III

Mean rank scores for intermediate moisture jackfruit dehydrated at 40±5^{0}C

Samples	Appearance	Colour	Flavour	Texture	Odour	Taste	After taste	Overall acceptability
T_1	2.50	2.85	2.60	2.75	2.90	3.15	3.15	3.05
T_2	3.20	3.75	2.15	2.60	2.35	2.05	2.30	2.25
T_3	4.10	3.70	4.60	4.60	4.25	4.70	4.80	4.55
T_4	4.05	3.55	4.20	3.90	4.05	4.00	3.75	4.15
T_5	1.15	1.15	1.45	1.15	1.45	1.10	1.00	1.00
Kendal's W test	0.744	0.681	0.783	0.779	0.671	0.911	0.894	0.877

B. Mean rank scores for intermediate moisture jackfruit dehydrated at 50±5^{0}C

Samples	Appearance	Colour	Flavour	Texture	Odour	Taste	After taste	Overall acceptability
T_1	2.80	2.90	3.10	2.70	2.75	3.05	2.60	3.40
T_2	2.55	2.80	2.50	2.50	3.25	2.25	2.30	2.20
T_3	4.10	3.85	4.25	4.50	3.85	4.70	4.65	4.65
T_4	3.75	3.70	3.45	3.85	3.55	3.70	3.95	3.65
T_5	1.80	1.75	1.70	1.45	1.60	1.30	1.50	1.10
Kendal's W test	0.404	0.355	0.413	0.611	0.420	0.723	0.687	0.804

C. Mean rank scores for intermediate moisture jackfruit dehydrated at 60±5^{0}C

Samples	Appearance	Colour	Flavour	Texture	Odour	Taste	After taste	Overall acceptability
T_1	3.05	3.45	3.10	2.85	2.75	2.70	3.15	2.95
T_2	2.75	2.75	2.95	2.75	3.40	3.20	3.20	2.60
T_3	3.90	3.60	4.10	4.15	3.80	4.25	4.10	4.25
T_4	4.10	4.15	3.85	4.05	3.75	3.75	3.55	4.00
T_5	1.20	1.05	1.00	1.20	1.30	1.10	1.00	1.20
Kendal's W test	0.638	0.706	0.712	0.632	0.612	0.655	0.688	0.706

APPENDIX IV

A. Mean rank scores for IM jackfruit at 2 months after storage in different packaging materials

Samples		Appearance	Colour	Flavour	Texture	Odour	Taste	After taste	Overall acceptability
T_1	Ambient	4.90	3.30	4.90	4.20	3.80	4.80	6	5.90
	Low temperature	6.60	6.40	6.50	6.20	5.90	6.50	6.20	6.80
T_2	Ambient	3.60	4.30	3.60	3.90	3.10	3.00	3.50	3.20
	Low temperature	5	4.70	5.20	4.70	4.60	5.10	4.90	4.60
T_3	Ambient	4.00	4.30	4.50	4.50	3.50	3.30	3.10	2.50
	Low temperature	2.90	3.50	4.50	4.80	4.20	3.90	4.50	4.20
T_4	Ambient	3.60	3.20	3.30	3.90	2.00	2.30	3.80	2.90
	Low temperature	2.60	3.10	2.00	2.30	3.10	2.20	2.20	1.60
T5	Ambient	4.90	5.00	4.80	3.60	5.50	4.90	3.30	4.20
	Low temperature	2.60	2.40	2.90	3.00	2.40	2.60	2.60	3.30
T6	Ambient	3.50	3.70	3.20	3.30	5.00	5.20	3.60	4.10
	Low temperature	3	2.70	2.30	2.30	2.80	2.70	2.60	2.10
T7	Ambient	3.50	4.20	3.70	4.60	5.10	4.50	4.70	5.20
	Low temperature	5.30	5.20	4.60	4.70	5.00	5.00	5.00	5.40

A. Mean rank scores for IM jackfruit at 4 months after storage in different packaging materials

Samples	Appearance	Colour	Flavour	Texture	Odour	Taste	After taste	Overall acceptability
T_1	4.85	5.35	5.55	4.80	4.95	5.65	5.45	5.75
T_2	1.25	1.95	3.90	2.80	3.70	3.55	3.50	3
T_3	3.95	3.65	3.80	4.10	4.20	3.45	4	4.20
T_4	4.25	4.20	4.45	5.05	3.40	4.65	4.70	4.80
T_5	4.45	4.15	3.35	3.90	3.85	4.25	3.75	3.75
T_6	4.90	4.70	3.30	3.70	4.20	2.65	3.10	3.50
T_7	4.35	4.00	3.65	3.65	3.70	3.80	3.50	3
Kendall's W test	0.406	0.283	0.166	0.143	0.072	0.235	0.194	0.258

C. Mean rank scores for IM jackfruit at 6 months after storage in different packaging materials

Samples	Appearance	Colour	Flavour	Texture	Odour	Taste	After taste	Overall acceptability
T_1	4.30	5.25	5.60	4.45	4.60	4.05	4.85	5.55
T_2	1.15	2	3.20	2.60	3.30	2.80	3	2.70
T_3	3	2.50	2.90	3	4.35	3.20	3.35	3.05
T_4	3.85	3.30	4.00	4.80	3.70	4.30	4.15	3.45
T_5	5.70	5.95	4.05	5.45	5.10	6.85	5.85	6.30
T_6	4.45	4.15	3.60	3.40	3.10	3.10	3.35	3.60
T_7	5.55	4.85	4.65	4.30	5.00	3.70	3.45	3.35
Kendall's W test	0.635	0.539	0.229	0.268	0.484	0.461	0.280	0.447

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DEVELOPMENT, PACKAGING AND STORAGE OF INTERMEDIATE MOISTURE JACKFRUIT (*Artocarpus heterophyllus* L.)

By

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ABSTRACT

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ABSTRACT

Jackfruit, a tropical composite fruit with delicious, succulent bulbs, is rich in carbohydrates, protein, potassium, calcium, iron, vitamin A, B, and C. The huge size and high perishability are major bottlenecks in its post harvest handling. As a result of the recognition that jackfruit is under-utilised but has considerable potential for alleviating malnutrition and income generation, appropriate methods for post harvest handling, processing and product diversification are to be developed.

In this circumstance, a study on "Development, packaging and storage of intermediate moisture jackfruit (*Artocarpus heterophyllus* L.) was conducted in the Department of Processing Technology, College of Horticulture, Vellanikkara. Intermediate Moisture (IM) foods are semi moist foods having ideal water activity between 0.65-0.90 and some of their water is bound by glycerol, sorbitol, salt or certain organic acids, thus preventing the growth of many micro organisms. As the intermediate moisture products are characterized by semi moist consistency, these foods have enough moisture content to permit easy chewing but low enough water to prevent spoilage.

Firm, ripe bulbs of variety Muttam Varikka were subjected to additive infusion by steeping in a solution containing a binding agent (2%) in combination with a humectant (sucrose-60%), an antioxidant (ascorbic acid-0.2%) and a preservative (potassium metabisulphite-0.2%), for 12 hours. The binding agents used were calcium lactate, sodium alginate, corn starch and cassava starch. After additive infusion, the bulbs were dehydrated in a drier developed by the NIST, Thiruvananthapuram at three different temperatures viz 40±5, 50±5 and 60±5^{0}C.

Moisture content and water activity were found to be in the range of 16.20 to 22.54 per cent and 0.76 to 0.80, respectively. Moisture content, water activity, pH, vitamin C, total carotenoids, total flavanoids and microbial count showed a

declining trend with increase in dehydration temperature. TSS, titratable acidity and sugar content increased with increase in dehydration temperature. Observations on physico chemical characteristics revealed significant differences only in pH and vitamin C content of the product. Therefore, the treatment possessing maximum organoleptic quality and minimum microbial load was selected as the best one. Thus intermediate moisture jackfruit containing corn starch as the matrix binding agent in combiantion with other additives was selected for storage studies

The intermediate moisture jackfruit thus developed was enclosed in seven types of packaging materials (LDPE 200 gauge, plastic trays over wrapped with cling film, high impact polystyrene boxes (HIPS), laminated aluminium foil pouches, rigid plastic boxes and glass containers) followed by storage under two conditions (ambient and low temperature).

Samples stored under ambient conditions became unmarketable after two months of storage, whereas the ones stored under refrigerated condition was marketable upto six months. LDPE pouches (100 gauge) and glass containers showed minimum changes in physico-chemical characteristics of the product as compared to other packaging materials.

A declining trend in moisture, water activity, pH, non reducing sugar, vitamin C, total carotenoids and total flavanoids was observed during storage, whereas TSS, acidity, total ash, reducing sugar, total sugar and non enzymatic browning showed an increasing trend. Organoleptic quality declined gradually during storage, but the scores were within the acceptable range in refrigerated samples.