SHELF LIFE OF BREADFRUIT
(*Artocarpus altilis* (Park) Fosberg)

By

CHITRA K. PILLAI

THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Science in Horticulture

Faculty of Agriculture
Kerala Agricultural University

Department of Processing Technology
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680 656
KERALA, INDIA

2001

DECLARATION

I hereby declare that the thesis entitled **"Shelf life of breadfruit (*Artocarpus altilis* (Park) Fosberg)"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

Vellanikkara
6-11-'01

CHITRA K. PILLAI

Dr. P. JACOB JOHN
Associate Professor
Department of Processing Technology
College of Horticulture
Vellanikkara, Thrissur

Vellanikkara
November, 2001

CERTIFICATE

Certified that the thesis, entitled **"Shelf life of breadfruit (*Artocarpus altilis* (Park) Fosberg)"** is a record of research work done independently by **Miss. Chitra K. Pillai,** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

P. Jacob John
Chairman, Advisory Committee

CERTIFICATE

We, the undersigned members of the Advisory Committee of **Miss. Chitra K. Pillai,** a candidate for the degree of **Master of Science in Horticulture** with major in **Processing Technology**, agree that the thesis entitled **"Shelf life of breadfruit (*Artocarpus altilis* (Park) Fosberg)"**may be submitted by **Miss. Chitra K. Pillai,** in partial fulfilment of the requirement for the degree.

15/12/01

Dr. P. Jacob John
Associate Professor and Head i/c
Department of Processing Technology
College of Horticulture
Vellanikkara, Thrissur
(Chairman)

15/12/01

Dr. Sarah. T. George
Associate Professor
Department of Pomology and Floriculture
College of Horticulture
Vellanikkara
(Member)

15/12/01

Dr. A. Augustin
Associate Professor
AICRP on M&AP
College of Horticulture
Vellanikkara
(Member)

15/12/01

Dr. P.B. Pushpalatha
Assistant Professor
Department of Processing Technology
College of Horticulture
Vellanikkara
(Member)

16/5/2002

EXTERNAL EXAMINER
Dr. N. Kumar
Professor and Head
Department of Fruit Crops
HC+RI, TNAU, Coimbatore.

ACKNOWLEDGEMENT

I wish to place on record my profound sense of gratitude to my guide Dr. P. Jacob John, Associate Professor and Head i/c, Department of Processing Technology for his able guidance, ever willing help, constructive criticism, constant encouragement and above all the extreme patience, understanding and whole hearted co operation rendered throughout the course of the study. I am indeed honoured to submit my thesis under his guidance.

My sincere obligations are due to Dr. Sarah T. George, Associate Professor, Department of Pomology and Floriculture and member of the Advisory Committee for her critical suggestions, sustained interest and support extended to me all throughout the investigation.

I am respectfully thankful to Dr. A. Augustin, Associate Professor, AICRP on M & AP and member of the Advisory Committee for the valuable help and relevant suggestions, which I have received at different stages of my work.

I sincerely acknowledge the warm and voluntary assistance rendered by Dr. P. B. Pushpalatha, Assistant Professor, Department of Processing Technology and member of the Advisory Committee. Her constant interest and encouragement have helped me a lot in the completion of this work.

My profound thanks are due to Sri. S. Krishnan, Associate Professor, Department of Agricultural Statistics for his guidance throughout the statistical analysis of the data.

I wish to express my deep gratitude to Dr. V. K. Raju and Dr. K. B. Sheela, Associate Professors, Department of Processing Technology, for all the encouragement and help rendered during the course of the study.

It is a pleasant privilege to express my gratitude to Radhechi and Krishnettan for their immense help and support. Kind help and co operation extended by Vijayan chettan and Devaki chechi are sincerely acknowledged.

I am grateful to JMJ Computer Centre, Thottappady for the neat typing of the manuscript.

I extend my sincere gratitude to Basheer for the neat scanning of the photographs.

The award of KAU Junior Fellowship is gratefully acknowledged.

I am thankful to all my classmates, seniors and juniors for their support and co operation. A special work of thanks to Mayachechi for her everwilling help and to Romy chechi for the excellent photographic work.

The love, support and encouragement of my dear friends Jyothi, Ani.P., Ani, Zahi, Saifu, CV, Veena, Sheron, Shylu, Glenda, Deepa, Jayashree, Deeparaj, Fillite, Shanu, Prince, Deepthy, Labi, Teena and Swapna are gratefully acknowledged. I am in dearth of words to express my thanks to Subunu, Joseph and Neena for keeping up my spirit when I found the going too tough.

I owe the successful completion of the thesis to my Achan, Amma, Chettan, Chechi and Unnikuttan whose boundless affection and prayers have guided me at each and every point of this venture.

Above all, I submit this small venture before GOD ALMIGHTY for blessing me with good health and confidence throughout the study.

Chitra K. Pillai

Affectionately
dedicated to my
Achan and Amma

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABBREVIATIONS

µm	- micrometers
RH	- Relative humidity
ppm	- parts per million
t/ha	- tonnes/hectare
PE	- polyethylene
PP	- Polypropylene
PLW	- Physiological loss in weight
SD	- Sun dried
MD	- Mechanically dried
MW	- Microwave oven dried
KMS	- Potassium metabisulphite
MAP	- Modified atmosphere packaging
CAS	- Controlled atmosphere storage
viz	- namely
DAS	- Days after storage
WAS	- Weeks after storage
MAS	- Months after storage
IU	- International Units

Introduction

INTRODUCTION

Breadfruit, *Artocarpus altilis* formerly known as *Artocarpus incisus* or *A. communis* belonging to the family Moraceae provides staple food for the people of South Pacific. Its introduction to the New world was connected with the memorable voyage of Captain William Bligh, who had seen the fruit in the Pacific Islands and considered it to be a promising foodstuff for the future.

Breadfruit is not consumed in the ripe stage in the popular sense of the term 'fruit'. It contains considerable quantities of starch and is consumed mostly as a vegetable and seldom eaten raw. In addition to being a good source of carbohydrates, it also has fair quantities of calcium, potassium and phosphorus (Graham and DeBravo, 1981). Though not high in protein, the amino acid profile of its protein was found to be favourable (Arcelay and Graham, 1984).

In the West Indies and on the American mainland from Mexico to Brazil, the breadfruit tree is grown in indoor yards and the fruit is sold in the market in the fresh form. It is also grown in countries like India, Tahiti, New Guinea, Colombia and as far as Western Micronesia.

In India, the major harvesting season starts from March to June; the main problem associated with its utilization is the high perishability. The fruit ripens in a short period of three to four days at ambient condition. Within this period, the fruit is transformed from green firm stage to ripe soft sweet product making it susceptible to mechanical damage and pathological spoilage. It is a fast ripening "climacteric" fruit resulting in faster depletion of stored food reserves.

Besides the high ambient temperature prevailing in most tropical conditions, heat build up, moisture loss, faster respiration rate and breakdown of cellular organisation leads to softening, colour development and other biochemical changes associated with the ripening making it unfit to use as a vegetable.

Therefore it is highly imperative to carry out investigations to curtail the respiration rate, thereby bringing an extension to the shelf life of the material.

Low temperature storage is a time tested storage technique and therefore needs to be explored giving various pre-packaging treatments. Attempts are also to be made to store them in a semi processed or minimally processed form under low temperature, so that it can be made available in a "ready to cook" form during the off season. Efforts have also been made to keep the materials in a dehydrated form with suitable pre-treatments and packages to make them available almost round the year.

Therefore the present investigation entitled "Shelf life of breadfruit (*Artocarpus altilis* (Park) Fosberg) was laid out with the following major experiments.

1. Storage of fresh fruits both at ambient and refrigerated temperature.
2. Storage of minimally processed breadfruit slices
3. Dehydration and subsequent packaging studies.

Review of Literature

REVIEW OF LITERATURE

Breadfruit, *Artocarpus altilis*, a good source of carbohydrates was considered to be a staple food for the people of the South Pacific some time ago, but now it is also cultivated widely in the Malay Archipelago, India, Tahiti, West Indies, New Guinea and Columbia. Earlier the fruit was known as *Artocarpus communis* Forst, *Artocarpus incisus* Linn (Barrau, 1957) but the most widely accepted name now is *Artocarpus altilis* (Park) Fosberg (Stone, 1974). It is a tropical fruit crop growing to a height of 12-30 m, having a straight trunk with thick buttresses and branchlets. The leaves are alternate and crowded at the tip of the branchlets. The inflorescences are unisexual-monoecious and axillary. The male inflorescences are yellow in colour, cleavate, drooping or curving downwards. The female inflorescences are globose-ovoid with flowers crowded together at the base. The fruit is a syncarp, greenish yellow in colour, spiny and commonly seedless (Ochse, 1931). The tree starts yielding 5-6 years after planting. The average yield per tree is about 200 fruits with weight ranging from 0.5-3 kg per fruit (CSIR, 1948).

Purseglove (1968) reported that fruits mature between 60-90 days after setting of inflorescence depending upon the variety, climate, soil and cultural conditions. The fruit is harvested when still firm, hard and unripe.

Graham and DeBravo (1981) separated the breadfruit into three different parts viz. the skin, stem and heart and pulp. It is the fleshy pulp of the fruit that is usually consumed; and it is rich in starch, protein, minerals and certain vitamins. The major constituents of the fruit, besides moisture are starch, sugars, protein and crude fibre. These constituents vary at the four different stages of maturity viz., very immature, immature, mature and very mature stages of development of fruit on the tree. Wootton and Tumaalii (1984b) studied the variations in the composition of seven varieties of breadfruit from Samoa which were harvested at the same four stages.

Breadfruit is not consumed in the ripe stage in the popular sense of the term 'fruit'. The fully mature but unripe fruit is used as vegetable (Bowers, 1981). Most breadfruit is consumed locally but there is a growing export trade from the Caribbean to Europe and North America, serving the ethnic market (Roberts-Nkrumah, 1993). The extreme perishability of the fruit especially hampers this export trade. The extreme perishability is due to its high rate of respiration, leading to quality deterioration within a day or two of harvest (Bates *et al.*, 1991).

Therefore development of appropriate storage and processing techniques to extent its life and marketability assumes great significance. Short term preservation methods like pre-packaging along with low temperature storage, steeping preservation and modified atmosphere storage can prolong the storage life for one or two weeks. Long term preservation methods like dehydration, canning and fermentation could ensure its availability throughout the year.

Literature on related works hitherto carried out at different places is reviewed and presented here under the titles:

2.1 Handling and storage of fresh breadfruit

2.2 Dehydration and packaging studies

2.1 Handling and storage of fresh breadfruit

2.1.1 Yield

A mature breadfruit tree yields about 200 fruits per year, with an average fruit weight of 0.5 to 3 kg (CSIR, 1948, Purseglove, 1968). In Nigeria, a fruit weighing about 1.5 kg could be obtained for the equivalent of US $ 1.0 and was sufficient to feed four adults (Omobuwajo and Wilcox, 1989). Van Wissen (1978) also estimated the average yield as 20 t/ha, where the density of planting is 100 trees/ha. Wootton and Tumaalii (1984a) estimated that this would result in about 6 t/ha of dry flour, an yield comparable to that of corn or maize.

2.1.2 Maturation and harvest

Fruits after 15-19 weeks after inflorescence emergence were reported to have the most acceptable eating quality (Worrell and Carrington, 1997). Earlier other parameters were used for deciding the harvest maturity of the fruit. Slight lightening of skin colour during maturation was noticed by Coronel (1990). Breadfruit contains a range of secondary metabolites (Altman and Zito, 1976). The most predominant volatiles were found to be alcohols (Iwaoka *et al.*, 1994). But the fruit odour exuded is subtle and doesn't appear to change with maturation. Another maturity index used is the skin topography with its domed polygonal segments (Marriott *et al.*, 1979). These polygons start out closely packed each domed and almost pyramidal in shape and then expand and flatten as the fruit attains full size. A final indicator of maturation is the appearance on the skin of tiny balls and rivulets of latex which cover a large proportion of fruit surface (Reeve, 1974).

2.1.3 Fruit ripening

Biale and Barcus (1970) classified breadfruit as climacteric type, with a significant rise in respiration rate at the peak stage of ripening. Graham and DeBravo (1981) found that the total sugar content of the different parts of the fruit showed an increase accompanied by fruit softening, as the fruit passed from mature to very mature stage while on the tree. Wootton and Tumaalii (1984b) made a similar observation in seven varieties of breadfruit in Samoa and found that an increase in sucrose content with concomitant decrease in starch at a very mature stage of harvest. So the fruits will ripen on the tree itself, if harvest is delayed. So harvesting the fruit at the appropriate stage of maturity is important to extend the post-harvest storage life and maintain processing quality (Narasimham, 1990).

2.1.4 Composition of fruits

The fleshy pulp of the fruit, which is the edible portion, is rich in starch, proteins, minerals and vitamins. The content of starch and proteins vary from very immature stage to very mature stage of development of fruit on the tree. The minerals present in breadfruit in mg/100g are calcium (195), phosphorus (90-146), potassium (1630), sodium (2.8), magnesium (80), iron (1.9-2.4), copper (0.3), zinc (0.4) and manganese (0.2). Among these, calcium, phosphorus, magnesium and iron are present in considerable quantities. Vitamin A (24.4 IU/100g), vitamin C (23mg/100g) niacin (2.4mg/100g) and riboflavin (0.2mg/100g) are the vitamins reported (CSIR, 1948; Graham and Debravo, 1981). The vitamin and mineral content of the fruit varies from region to region. A higher content of minerals was reported from Indian breadfruit than from Puerto Rico. Wootton and Tumaalii

(1984b) found that Samoan breadfruit had similar amounts of iron, sodium and calcium, about half as much potassium and four times as much phosphorus as the breadfruit from Puerto Rico observed by Graham and DeBravo (1981).

Correa *et al.* (1970), Loos *et al.* (1981) and Tumaalii (1982) conducted studies on the starch isolated from breadfruit pulp. Loos *et al.* (1981) reported an amylose content of 18.2 per cent in breadfruit starch. The physico-chemical properties of the starch showed that the starch granules are small in size, ranging from 10 to 20 μm in diameter and the shape ranges from spherical to oval or elliptical.

Achinewhu (1982) studied the fatty acid composition of the fat in breadfruit pulp. He showed palmitic, stearic, oleic and linoleic acid as the predominant ones among 11 fatty acids.

2.1.5 Storage of breadfruit

Breadfruit, like other tropical fruit, softens and deteriorates rapidly under ambient tropical conditions of high temperature and humidity. This softening can begin two to three days after harvest under these conditions. Since the fruits are inedible once ripened, the goal of storage must be to delay the onset of ripening.

Marriott *et al.* (1979) reported that the storage period between harvesting and softening was greater for fruit harvested at partially mature stage than for fully mature fruit; fruits which have been harvested by picking or catching had a longer storage life than those allowed to fall to the ground.

In Jamaica, breadfruits were preserved traditionally by steeping the fruits under water for a period of seven days. However, by this method splitting of the fruit skin accompanied by softening of fruit was observed (Thompson *et al.*, 1974). They also studied the effects of temperature, packing, harvesting method and cultivar on the storage life of the fruit. Packing the fruits in polyethylene bags delayed the softening of fruits and they remained edible for a week. Passam *et al.* (1981) successfully stored Trinidad breadfruit cv. Whiteheart in polyethylene bags at 14°C for 14 days.

Sankat and Maharaj (1993), noticed that fresh fruits could be stored for a week at ambient temperature (28°C) when individually packaged in sealed polyethylene bags of 100 gauge. Coating of fresh fruits with "Fresh Mark FM-51V", undiluted was also helpful in storing fruits for seven days at ambient temperature.

Suryanathmisae (1988) developed wooden storage structures at field level for the storage of freshly harvested breadfruit in New Guinea.

Microbes associated with field spoilage of the fruit was investigated by Omobuwajo and Wilcox (1989). They found that *Aspergillus niger, A. sydowii, A. ochraceous, A.versicolor, Mucor varians, Rhizopus stolonifer, Staphylococcus aureus* and *S. epidermis* were associated with spoilage of the fruit in the field. They concluded that fungi and bacteria get access into the fruit through the natural openings in the epidermis. Fumigation of the tree with a suitable fungicide at the onset of flowering and/or shortly after emergence of the fruit was suggested to control the microbiological spoilage of the fruit.

2.1.6 Refrigerated storage

Refrigerated storage has been shown to extend the post harvest life of most produce (Kader, 1992) and breadfruit is no exception, 12-13°C being optimal (Thompson *et al.*, 1974). Marriott *et al.* (1979) reported that the storage life of breadfruit could be increased by packing it in polyethylene bags and holding it at 13°C.

Tropical fruits are generally susceptible to chilling injury, if stored at temperatures below 10-12°C. Worrell and Carrington (1997) showed that while shelf life was considerably extended at 7 and 10°C, such fruit when removed from storage failed to ripen normally displaying water soaked lesions with flesh browning, symptoms typical of chilling injury. This agreed with the observation of Thompson *et al.* (1974) that chilling injury in breadfruit is noticed at 2.5 and 7.5°C.

For many fruits; rapid removal of field heat and cooling to the optimum storage temperature can further extend post harvest life. This pre-cooling can be in the form of air cooling or hydro cooling. Compared with air cooling, hydro cooling can halve or quarter the time taken to cool breadfruit to 13°C storage temperature (Worrell and Carrington, 1997). For hydro cooling to be effective, it must be carried out in the field, immediately on harvest, as Maharaj and Sankat (1990) reported a positive response to immediate pre-cooling of breadfruit in chipped ice in the field.

Maharaj and Sankat (1989) noted that at ambient temperature (28°C) breadfruit undergo browning of the skin during ripening and attributed this to the normal degradative changes associated with ripening. This browning occurs even at optimal storage temperature (12-13°C) and is accelerated by such storage, even if ripening hasn't begun.

Application of emulsions or suspensions to fruit surfaces that dry to leave a chemical coating are thought to reduce water loss by blocking lenticels, stomata and other surface irregularities. Early attempts using fruit wax on breadfruit didn't significantly reduce softening or the rate of water loss at ambient temperature or 12.5°C (Thompson *et al.*, 1974). Worrell *et al.* (1994) tried four different coatings Sta-Fresh MP, Nutri-save, Semperfresh- F and a chitosan preparation. Only Sta-fresh significantly reduced water loss at both ambient temperature (25-28°C) and at 13°C. Softening was delayed by all coatings at 28°C but there was no significant effect at 13°C. In some cases, the coatings also encouraged fungal growth on fruit surface. In all cases, coatings led to the development of alcoholic aroma suggestive of anaerobiasis.

Brush coating of wax on the fruit surface before subjecting it to storage at 16°C was found to extend marketable shelf life of breadfruit to 18 days (Sankat and Maharaj, 1993). Waxing also delayed the symptoms of chilling injury compared to untreated fruits, as waxed fruits at 16°C showed complete browning only after 25 days of storage.

2.1.7 Minimal processing

Minimal processing of fruits involve cleaning, peeling, cutting, slicing and packaging without killing the tissues (Shewfelt, 1987). Such a product with living plant tissues is washed, given preservation treatment and packaged before distribution, so chances of microbial contamination is very less (Cantwell, 1992). Minimally processed fruits have certain advantages like convenience in use, supply in ready to cook form, reduction in size which enables easy handling and transportation (Siriphanich, 1993). The most important factor with regard to minimally processed fruits and vegetables is the maintenance of a high level of quality for an adequate duration subsequent to harvest (Gertmenian, 1992). Schlimme (1995) reported that minimally processed fruits are living tissues that undergo catabolism and respiration. So steps taken to reduce respiration rates can also reduce the rate of quality degradation and slow down biochemical changes that lead to tissue senescence. Packaging the produce in polymeric film, semi-rigid containers etc. can reduce the oxygen and increase the carbon dioxide concentration in the package atmosphere thereby slowing degradative processes.

Modified and controlled atmosphere storage can help maintain quality and extend the storage life by inhibiting metabolic activity, decay and especially ethylene biosynthesis and action (Kader, 1986). Modified atmosphere packaging is widely used for minimally processed fruits. Because of the perishability of the product the modified atmosphere in the package is often actively established, either by flushing with the desired atmosphere or by pulling a slight vacuum and then injecting a desired gas mixture (Brecht *et al.*, 1993).

Ramlochan (1991) used gaseous concentrations ranging from 2.5 to 5 per cent O_2 and 2.5 to 10 per cent CO_2 with 100 per cent RH in storage chamber. Based on biochemical and sensory analyses it was concluded that the best marketable life of 21 days was achieved with a combination of 2-5 per cent O_2 and 5 per cent CO_2 at 12°C.

John and Narasimham (1998) carried out minimal processing of breadfruit and they reported that slices of 2 x 2 x 1.25 cm^3 size, treated with 1000 ppm sulphur dioxide and stored at 28±2°C kept well for 30 days and the same slices at 0°C had a shelf life of 120 days. Also slices infiltered with 500 ppm SO_2 and packaged with CO_2 in the head space had superior colour, texture and taste.

2.2 Dehydration and packaging studies

2.2.1 Fermented product

The oldest process for the long-term preservation of breadfruit is fermentation. This was reported by a number of people such as Coenen and Barrau (1961), Mackenzie *et al.* (1964), Goodman (1972) and Cox (1980).

Although the process differs in minor details from place to place, it involves essentially, an anaerobic fermentation of the breadfruit in pits in the ground, under leaf coverings. The resulting product is a highly acidic paste which can be preserved for months to years. In Samoa, this paste is consumed by mixing with coconut cream or condensed milk and spread on slices of bread. In some places, this paste is baked like bread with the consistency of cheese. Whitney (1988) studied the microbiology associated with the pit fermentation of breadfruit. He, in his study reported that the sequence of organisms associated with the fermentation are *Micrococci, Periococci, Lactobacilli* and *Leuconostocs*. He also reported the total volatiles liberated during long-term pit fermentation found out by G.C. analysis; it includes 34 per cent ethanol, 17 per cent formic acid, 11 per cent iso amyl alcohol, 8.5 per cent butyric acid, 7 per cent propanol, 7 per cent iso propanol, 3.5 per cent acetic acid and 3 per cent propionic acid.

2.2.2 Dehydration of breadfruit

Breadfruit can be preserved by sun or artificial drying. The fruits picked at mature green stage is subjected to scraping to remove the skin and then the edible portion is cut into 10 mm slices which can be dried artificially at 49°C for four days reducing the moisture content to 8-10 per cent. These chips remain in good condition for two or three years if stored in airtight containers (Barrau, 1957).

Wootton and Tumaalii (1984b) and Graham and DeBravo (1981) studied in detail the feasibility of dehydrating breadfruit and subsequently making 'papad' like products from the dehydrated breadfruit flour. Reeve (1974) intensively studied the commercial dehydration potential of breadfruit both by tunnel drying and freeze drying techniques. Breadfruit slices of 0.25 x 0.5 x 0.5 inch size were blanched for three minutes in boiling water and then tunnel dried for four hours at 140°F. It reconstituted readily in either cold or hot water. Textural and culinary qualities of reconstituted samples were similar to those of freshly boiled or steamed samples. Freeze dried samples were also readily reconstituted in boiling water. Keeping quality of both forms of dried breadfruit was found to be good. No off odour was detected in the freeze dried slices when kept at room temperature for six months. The freeze dried slices were found to be more fragile than tunnel dried form.

Mathews *et al.* (1986) at the University of Puerto Rico carried out research on the utilisation of breadfruit pulp. Bates *et al.* (1991) reported on the preparation, stability and acceptability of chips made out of raw breadfruit. They succeeded in producing stable, crisp chips with lipid stability compared to potato chips.

Narasimham and John (1995) worked on controlled low temperature vacuum drying of dried breadfruit using a conventional freeze drier. They obtained a dehydrated product with the rate and extend of dehydration, shrinkage, rehydration and sensory quality equivalent to conventionally freeze dried product. The product had better quality than those obtained by vacuum and cross flow dried products.

Materials and Methods

MATERIALS AND METHODS

The present investigation on the shelf life of breadfruit was carried out at the Department of Processing Technology, College of Horticulture, Vellanikkara, Thrissur, Kerala during 2000-2001. Vellanikkara enjoys a warm humid tropical climate throughout the year.

Harvested fresh breadfruit remains acceptable only for one or two days under ambient conditions. In the present study attempts have been made to develop suitable methods for storing and packaging fruits as well as minimally processed slices of breadfruit without spoilage and also to develop a dehydration technique intended for long-term storage.

The whole programme was divided into three major experiments.

3.1 Storage of fresh breadfruit under ambient and refrigerated conditions

3.2 Storage of minimally processed breadfruit slices

3.3 Dehydration and subsequent packaging studies

3.1 Storage of fresh breadfruit under ambient and refrigerated conditions

3.1.1 Procurement of fruits

Breadfruits were collected from the ten year old trees grown in the orchard maintained by the Department of Pomology and Floriculture, College of Horticulture, Vellanikkara (Plate 1 & 2).

Harvesting of fruits was done in the morning hours, based on the maturity indices suggested by Graham and DeBravo (1981). The fruits were

Plate1. Tree bearing breadfruits

Plate 2. Branchlet bearing fruits

harvested without injury. They were then taken to the laboratory for further treatments.

The fruits were sorted for any spoilage and discolouration, if observed, such fruits were discarded.

3.1.2 Treatments

T_1 - Fruits wrapped individually with cling film

T_2 - Packaged in polyethylene (PE) bags of 250 gauge without ventilation

T_3 - Packaged in PE bags of 250 gauge with 4% ventilation

T_4 - Packaged in PE bags of 250 gauge with 4% ventilation after dipping the fruits in hot water (50 to 60°C for 3 min) and draining to dryness

T_5 - Packaged in PE bags of 250 gauge with 4% ventilation after dipping the fruits in hot water with 0.5 per cent $CaCl_2$

T_6 - Fruits wrapped individually in newspaper

T_7 - Plugging the cut end of the stalk using plastic tape to arrest the latex exudation immediately after harvest at the field itself

T_8 - Open stored (control)

T_9 to T_{15} - All the above treatments were repeated but stored under low temperature

3.1.3 Lay out

All the experiments were laid out in a Completely Randomised Design (CRD) with three replications each.

3.1.3.1 Experiment with cling film

Fully mature but unripe breadfruits were selected at random from the harvested lot. The fruits were washed and wiped dry with clean dry muslin cloth.

They were then weighed and wrapped individually with cling film (Klin wrap 300 mm of Flexo film wraps (India) Ltd; Aurangabad).

3.1.3.2 Ventilation

PE bags of size 25 x 20 cm^2 with 101 vents of 0.25 mm radius to make 4 per cent ventilation.

The PE bags were heat sealed using a heat sealing machine (Quickseal TM of Sevana (India) Ltd.).

3.1.4 Observations

Observations on both physical and chemical changes during storage were taken at daily intervals as detailed below.

3.1.4.1 Physical observations

3.1.4.1.1 Fruit shape

Fruits were categorised into round, oval or oblong shape by visual assessment.

3.1.4.1.2 Fruit weight

Weight of individual fruits were taken using an electronic balance (OHAUS 200 portable standard) with 100 mg accuracy.

3.1.4.1.3 Dimensions

Fruit length was measured in centimeters from the stalk end to the apex and diameter in the equatorial plane using a scale.

3.1.4.1.4 Volume

Fruit volume was determined in milli litres by water displacement method using a measuring cylinder.

3.1.4.1.5 Density

Density was computed by dividing weight by volume of the fruit.

3.1.4.1.6 Firmness

Firmness of the fruit was measured by penetrometer method using Effegi fruit pressure tester [Model PT 001 (0-5kg)] and expressed as kg cm^{-2}.

3.1.4.1.7 Number of days for ripening

Number of days to reach ripeness by mature fruit indicated by softening was recorded.

3.1.4.1.8 Physiological loss in weight (PLW)

The physiological loss in weight was calculated on the initial weight basis as suggested by Srivastava and Tandon (1968) and expressed as percentage.

$$\text{PLW (\%)} = \frac{\text{Initial weight - Final weight}}{\text{Initial weight}} \times 100$$

3.1.4.1.9 Termination of the observations

Observations were terminated when 50 per cent or more of the original sample were discarded as suggested by Kapitsmadi (1989).

3.1.4.2 Chemical analyses

Composite samples were withdrawn at random with respect to each treatment at regular intervals for estimation of starch, ascorbic acid, sugars, residual SO_2 and fibre.

The samples were washed then dried using clean dry muslin cloth. Sample preparation was carried out in a mixer grinder for the estimation of sugars, ascorbic acid and residual SO_2. The pulped samples were stored in a deep freezer without delay to avoid further degradation and used for remaining analyses.

The samples for estimation of starch and fibre were sliced and kept in hot air oven to dry and when completely dried was powdered and used for analyses.

Analytical grade of chemicals of standard companies were used for the purpose.

3.1.4.2.1 Starch

Acid-alkali digestion method suggested by Sadasavam and Manikam (1992) was employed for the determination of starch.

3.1.4.2.2 Total sugars

Total sugars were determined by Lane and Eynon method (Ranganna, 1986) and expressed as percentage.

3.1.4.2.3 Reducing sugars

Reducing sugar content was determined using Lane and Eynon method (Ranganna, 1986) and expressed as percentage.

3.1.4.2.4 Residual SO_2

Residual SO_2 was determined as per the method suggested by Ranganna (1986).

3.1.4.2.5 Ascorbic acid

Ascorbic acid content during the storage period was determined by 2,6-dichlorophenol indophenol dye method as suggested by Ranganna (1986).

3.1.4.2.6 Fibre

Determination of fibre in the material was done using the acid-alkali digestion method suggested by Chopra and Kanwar (1978).

3.2 Storage of minimally processed breadfruit slices

The experiment was carried out to extend the shelf life of minimally processed breadfruit slices. This is to facilitate the storage of breadfruit in a "Ready to cook" form. Minimal processing involve peeling, coring and slicing of the fruit into required size and then preserving it, while retaining its qualities near to fresh form.

3.2.1 Preparation of materials for minimal processing

Breadfruits were harvested in the early morning hours, without injuring the fruits. They were cleaned, peeled and sliced into pieces of 4 x 3 x 2 cm^3 size and blanched at 90°C for three minutes and subjected to the following treatments.

T_1 - Steeping in 1500 ppm SO_2 solution in 1:2 ratio

T_2 - Packaging with CO_2 gas

T_3 - Packaging with in-package fumigant

T_4 - Packaging with nitrogen gas

T_5 - Packaging under vacuum

T_6 - Open stored (control)

3.2.2 Gas/vacuum packaging

Materials after the preparation as stated above were placed in aluminium laminated pouches of size 12 x 18 cm^2 and placed in a Quickseal vacuum packaging machine (Sevana Electrical Appliances Pvt. Ltd.) three packets at a time. The machine has a chamber capacity of 500 x 400 x 150 mm^3 with two sealing heads (Plate 3).

For flushing with CO_2 or N_2 gas, the pouches in the machine were first evacuated of air and then flushed with the respective gases.

3.2.3 Observations

Observations for both physical and chemical changes during storage were taken on alternate days for fruits stored at ambient temperature, weekly for refrigerated samples and monthly for frozen samples.

3.2.3.1 Physical observations

Colour, texture, flavour and extend of spoilage by visual observations were noted.

3.2.3.2 Chemical analyses

Samples were drawn at random for each treatment for estimation of total and reducing sugars, starch, residual SO_2, ascorbic acid and fibre by adopting the procedures already mentioned in 3.1.4.2.

3.3 Dehydration and packaging studies

The experiment was conducted with the objective of developing a suitable dehydration technique as a means of long term storage. This will enable to ensure its availability almost round the year.

3.3.1 Preparation of materials

Fruits were harvested during morning hours without injury. It was cleaned, peeled, cored and sliced into pieces of approximate size 4 x 3 x 2 cm^3. Samples of 200g each were taken for different treatments.

Plate 3. Quickseal vacuum packaging machine

3.3.2 Treatments

T_1 - Blanched in 90°C water for five minutes, sun dried (SD) and packed in 250 gauge polyethylene (PE) bags (SD_{PE})

T_2 - Treatment same as above, but packed in 250 gauge polypropylene (PP) bags (SD_{PP})

T_3 - Blanched in 90°C water for five minutes, mechanically dried (MD) and packed in PE bags (MD_{PE})

T_4 - Treatment same as above, but packed in PP bags (MD_{PP})

T_5 - Blanched in 90°C water for five minutes, microwave oven dried (MW) and packed in PE bags (MW_{PE})

T_6 - Treatment same as above, but packed in PP bags (MW_{PP})

T_7 - Blanched in 90°C water with 0.3% citric acid for five minutes, sun dried and packed in 250 gauge PE bags

T_8 - Treatment same as above, but packed in PP bags

T_9 - Blanched in 90°C water with 0.3% citric acid for five minutes, mechanically dried and packed in PE bags

T_{10} - Treatment same as above, but packed in PP bags

T_{11} - Blanched in 90°C water with 0.3% citric acid for five minutes, microwave oven dried and packed in PE bags

T_{12} - Treatment same as above, but packed in PP bags

T_{13} - Blanched in 90°C water with 0.3% citric acid and 1500 ppm SO_2 for five minutes, sun dried and packed in 250 gauge PE bags

T_{14} - Treatment same as above, but packed in PP bags

T_{15} - Blanched in 90°C water with 0.3% citric acid and 1500 ppm SO_2 for five minutes, mechanically dried and packed in PE bags

T_{16} - Treatment same as above, but packed in PP bags

T_{17} - Blanched in 90°C water with 0.3% citric acid and 1500 ppm SO_2 for five minutes, microwave oven dried and packed in PE bags

T_{18} - Treatment same as above, but packed in PP bags

The PE and PP bags were heat sealed in the same way as that of fresh samples.

3.3.3 Blanching of breadfruit pieces

Breadfruit slices of approximate size 4 x 3 x 2 cm^3 were taken in a muslin cloth, 200g per batch and dipped in hot water at 90°C, maintained for five minutes and withdrawn for immediate cooling. These blanched samples were used for further drying treatments.

3.3.4 Drying methods

3.3.4.1 Sun drying

Freshly harvested breadfruit having 82 per cent moisture were peeled, cored, sliced and given pre-treatments. The samples were then dried to moisture content of 9 to 10 per cent.

3.3.4.2 Mechanical drying

A cabinet dryer with inner dimensions 0.9 x 1 x 0.61 m^3 with 2.5 KW heating capacity was used. Two stage dehydration was given to the samples. Temperature was maintained at 60°C for the first four hours and later at 50°C for the rest of the period of drying up to a final moisture content of 9 to 10 per cent.

3.3.4.3 Microwave oven drying

Microwave oven used for drying was T-23 Touch Electronic model manufactured by M/s.Kelvinator (India). The size of the oven was 394 x 279 x 213 mm^3 (inner dimensions) and 578 x 305 x 308 mm^3 (outer dimensions) with 23 litre capacity. The power output was 700 W with microwave frequency of 2450 Hertz. The non-ionising electromagnetic waves, when bombarded with food get absorbed and penetrate to a depth of 2 to 4 cm; thus they excite the molecules in the food and cause the molecules to vibrate 2,450 million times/s which cause friction and produce heat.

3.3.5 Observations

3.3.5.1 Physical characters

3.3.5.1.1 Dehydration ratio

Dehydration ratio was calculated as per the formula given by Pruthi *et al.* (1978).

$$\text{Dehydration ratio} = \frac{\text{Weight of breadfruit taken for dehydration}}{\text{Weight of dried breadfruit}}$$

3.3.5.1.2 Drying rate

Drying rate was found out using the method described by Narasimham and John (1995). Breadfruit slices kept for dehydration were taken at different intervals and their weight as percentage to original weight was found out.

The temperature ranged from 21.5°C to 35.7°C during the period of sun drying.

3.3.5.1.3 Shrinkage rate

For the determination of volume shrinkage, dimensions of random samples were measured using vernier calipers, before and after dehydration. Shrinkage was calculated (Ocansey, 1984) as below

$$\text{Per cent volume shrinkage} = \frac{\text{Initial volume - final volume after dehydration}}{\text{Initial volume}} \times 100$$

Per cent volume shrinkage was measured at regular intervals during drying to find out the shrinkage rate.

3.3.5.1.4 Shrinkage ratio

The shrinkage ratio was determined as per the formula given by Ocansey (1984).

$$\text{Shrinkage ratio} = \frac{\text{Final volume obtained after dehydration}}{\text{Initial volume}}$$

3.3.5.1.5 Reconstitution rate

Weighed samples of dried breadfruit were reconstituted with hot water and at regular intervals, the weight pickup was assessed using electronic balance.

3.3.5.1.6 Reconstitution ratio

Reconstitution ratio was calculated using the formula given by Pruthi *et al.* (1978).

$$\text{Reconstitution ratio} = \frac{\text{Weight of sample after maximum reconstitution}}{\text{Weight of original dried sample}}$$

Results

RESULTS

The results of the study "Shelf life of breadfruit" are presented under the following headings in this chapter.

1. Storage of fresh breadfruit under ambient and refrigerated conditions
2. Storage of minimally processed breadfruit slices
3. Dehydration and subsequent packaging studies

4.1 Storage of fresh breadfruit

The effect of different packaging and storage techniques on the shelf life of breadfruit under ambient and refrigerated temperatures are presented in Table 1 to 4.

4.1.1 Physiological loss in weight (PLW), under different storage techniques

Changes in PLW recorded on alternate days for both ambient and refrigerated storage of the fruit are presented in Table 1.

The fruits under different ambient storage treatments remained without any microbiological spoilage up to seven days. However, the softening of the fruits due to ripening made them unfit for consumption after five days of storage. Therefore data up to five days of storage alone were considered.

Fruits packed in unventilated polyethylene bags of 250 gauge (T_2) recorded the minimum PLW (1.62%) after the fifth day of storage; this was comparable with that of T_1 (1.64%) in which individual fruits were wrapped in

Table 1. Physiological loss in weight of bread fruit under different storage techniques

Treatments	PLW (%)							
	Ambient temperature			Refrigerated temperature				
	0 DAS	3 DAS	5 DAS	0 DAS	3 DAS	5 DAS	7 DAS	9 DAS
T_1	0	1.36^{a}	1.64^{a}	0	1.07^{a}	1.17^{a}	1.40^{a}	1.52^{a}
T_2	0	1.34^{a}	1.62^{a}	0	1.23^{a}	1.33^{a}	1.91^{a}	1.91^{a}
T_3	0	1.81^{ab}	2.20^{ab}	0	1.16^{a}	0.87^{a}	1.87^{a}	1.99^{a}
T_4	0	1.71^{ab}	2.03^{ab}	0	1.01^{a}	1.31^{a}	1.64^{a}	1.99^{a}
T_5	0	1.61^{ab}	2.14^{ab}	0	1.04^{a}	1.31^{a}	1.53^{a}	1.73^{a}
T_6	0	2.25^{bc}	3.05^{b}	0	2.05^{b}	2.74^{b}	3.23^{b}	3.50^{b}
T_7	0	2.68^{c}	2.56^{ab}	0	2.24^{b}	3.15^{bc}	3.51^{b}	4.42^{c}
T_8	0	3.40^{d}	4.54^{c}	0	2.74^{c}	3.24^{c}	3.70^{b}	4.23^{c}

The values represent means of 3 replications
The values having different superscripts differ significantly at 5% level

cling film. The PLW for the rest of the treatments ranged between 2.03 per cent to 4.54 per cent with the control fruits showing the maximum PLW (4.54%).

The same treatments when stored under low temperature (7 ± 2°C), the life in all the treatments were extended up to nine days, with the minimum PLW recorded in those fruits wrapped with cling film T_1 (1.52%), while the control fruits showed a value of 4.23 per cent. The PLW of the treatments T_2, T_3, T_4 and T_5 were on par.

4.1.2 Firmness of breadfruit under different storage techniques.

Loss of firmness of the fruit is considered as an indicator of ripening. Fruits having an initial firmness value of more than 5 kg/cm^2 were maintained for five days at ambient temperature under different treatments. Maximum fruit firmness was recorded in the treatment T_2 at the end of five days (3.80 kg/cm^2), which was significantly different from other treatments. Maximum softening was recorded by the treatment T_6 for the same time period, while T_1, T_7 and T_8 were on par.

When stored under refrigeration, the same treatment (T_2) recorded the maximum value for firmness (2.13 kg/cm^2) after nine days of storage retaining the fruits in a marketable condition with a slight browning on the skin surface, while the control fruits recorded the minimum value of 1.82 kg/cm^2 after the same period of storage. All the other treatments recorded intermediate values (Table 2).

Table 2. Firmness of bread fruit under different storage techniques

Treatments	Fruit firmness (kg/cm²)							
	Ambient temperature			Refrigerated temperature				
	0 DAS	3 DAS	5 DAS	0 DAS	3 DAS	5 DAS	7 DAS	9 DAS
T_1	>5	4.80^{ab}	3.50^{c}	>5	4.88^{a}	3.77^{a}	2.23^{ab}	2.10^{a}
T_2	>5	4.80^{ab}	3.80^{a}	>5	4.83^{ab}	3.82^{a}	2.25^{a}	2.13^{a}
T_3	>5	4.78^{ab}	3.38^{cd}	>5	4.72^{b}	3.37^{b}	2.10^{ab}	2.00^{ab}
T_4	>5	4.92^{a}	3.38^{cd}	>5	4.77^{ab}	3.52^{b}	2.05^{ab}	2.00^{ab}
T_5	>5	4.83^{ab}	3.65^{b}	>5	4.80^{ab}	3.53^{b}	2.18^{ab}	2.07^{ab}
T_6	>5	4.75^{b}	3.32^{d}	>5	4.75^{ab}	3.48^{b}	2.12^{ab}	1.93^{a}
T_7	>5	4.83^{ab}	3.48^{c}	>5	4.75^{ab}	3.43^{b}	2.03^{ab}	1.97^{abc}
T_8	>5	4.70^{b}	3.47^{c}	>5	4.80^{ab}	3.33^{b}	2.00^{b}	1.82^{a}

The values represent means of 3 replications

The values having different superscripts differ significantly at 5% level

4.1.3 Chemical parameters

The influence of storage techniques on the development of sugars, breakdown of starch and crude fibre and changes in vitamin C content are given in Tables 3a, 4a and 3b, 4b at ambient and refrigerated temperatures respectively.

4.1.3.1 Starch

Irrespective of the treatments, under both ambient and refrigerated temperatures, a reduction in the starch content was observed, only the extend of decrease varied, with the least decrease observed in T_2, where the fruits were kept in unventilated polyethylene bags (59.31%) after five days of storage under ambient conditions. This was significantly different from all the other treatments with the next best value recorded by T_1 where fruits were wrapped in cling film (59.19%). Maximum starch breakdown was observed in control fruits (54.22%).

The trend was similar when the storage temperature was reduced to $7 \pm 2°C$, but the rate of breakdown of starch was lower. Maximum starch content was observed in T_2 (60.81%) after nine days of storage. The value for T_1 was on par with T_2 while the control fruits recorded the lowest value of 57.53 per cent.

4.1.3.2 Total sugars

Concomitant to the reduction in the starch content, an increase in the total sugars were observed in all the eight treatments irrespective of the storage temperatures, whether ambient or refrigerated. T_2 recorded the lowest values (8.37% and 7.10%) at ambient and refrigerated storage respectively after five days and nine days of storage; whereas the control samples recorded the maximum

Table 3a. Starch, total sugars and reducing sugars of breadfruit under different ambient storage techniques

Treatments	Starch (%)			Total sugars (%)			Reducing sugars (%)		
	0 DAS	3 DAS	5 DAS	0 DAS	3 DAS	5 DAS	0 DAS	3 DAS	5 DAS
T_1	68.70	63.75^{b}	59.19^{b}	5.25	6.91^{a}	9.12^{b}	1.03	1.17^{ab}	2.75^{b}
T_2	68.70	63.93^{a}	59.31^{a}	5.25	6.71^{a}	8.37^{a}	1.03	1.12^{a}	2.33^{a}
T_3	68.70	62.14^{e}	57.69^{c}	5.25	7.62^{bc}	9.44^{bc}	1.03	1.25^{ab}	3.02^{b}
T_4	68.70	62.48^{c}	56.78^{d}	5.25	7.84^{bcd}	9.45^{bc}	1.03	1.25^{ab}	2.83^{b}
T_5	68.70	62.53^{c}	57.72^{c}	5.25	8.09^{cd}	9.09^{b}	1.03	1.28^{ab}	3.06^{b}
T_6	68.70	61.99^{f}	54.42^{f}	5.25	7.43^{b}	9.13^{b}	1.03	1.43^{b}	2.92^{b}
T_7	68.70	62.21^{d}	55.18^{e}	5.25	8.11^{cd}	9.20^{c}	1.03	1.39^{ab}	2.88^{b}
T_8	68.70	61.80^{g}	54.22^{g}	5.25	8.25^{d}	9.70^{c}	1.03	1.43^{b}	3.07^{b}

The values represent means of 3 replications
The values having different superscripts differ significantly at 5% level

Table 3b. Starch, total sugars and reducing sugars of breadfruit stored under different techniques in refrigerated condition

Treat-ments	Starch (%)				Total sugars (%)				Reducing sugars (%)			
	0 DAS	3 DAS	7 DAS	9 DAS	0 DAS	3 DAS	7 DAS	9 DAS	0 DAS	3 DAS	7 DAS	9 DAS
T_1	68.70	66.38^{a}	64.28^{a}	60.43^{a}	5.25	5.89^{a}	7.13^{b}	7.59^{b}	1.03	1.09^{a}	3.34^{b}	3.50^{ab}
T_2	68.70	66.47^{a}	64.07^{ab}	60.81^{a}	5.25	5.78^{a}	6.65^{a}	7.10^{a}	1.03	1.07^{a}	3.13^{a}	3.41^{a}
T_3	68.70	65.36^{b}	62.77^{cd}	60.18^{ab}	5.25	6.67^{b}	7.44^{bc}	8.03^{c}	1.03	1.17^{b}	3.48^{bc}	3.73^{abc}
T_4	68.70	65.29^{bc}	63.01^{bc}	59.14^{bc}	5.25	6.62^{b}	7.43^{bc}	7.95^{bc}	1.03	1.27^{de}	3.48^{bc}	3.79^{bc}
T_5	68.70	65.73^{b}	62.71^{cd}	60.11^{ab}	5.25	6.65^{b}	7.48^{bc}	8.06^{c}	1.03	1.23^{cd}	3.45^{b}	3.84^{bc}
T_6	68.70	64.41^{de}	61.64^{d}	57.64^{d}	5.25	6.50^{b}	7.78^{cd}	8.14^{c}	1.03	1.20^{bc}	3.66^{cd}	4.10^{cd}
T_7	68.70	64.81^{cd}	62.57^{cd}	58.20^{cd}	5.25	6.79^{b}	7.89^{d}	8.21^{c}	1.03	1.32^{cf}	3.65^{cd}	4.09^{cd}
T_8	68.70	64.06^{e}	61.54^{d}	57.53^{d}	5.25	6.89^{b}	8.00^{d}	8.32^{c}	1.03	1.37^{f}	3.71^{d}	4.24^{d}

The values represent means of 3 replications

The values having different superscripts differ significantly at 5% level

values of 9.7 per cent and 8.32 per cent after the same storage periods for ambient and refrigerated storage respectively. Under refrigerated storage the treatments T_3, T_5, T_6 and T_7 were on par with the control fruits.

4.1.3.3 Reducing sugars

Formation of reducing sugars is not a desirable quality as far as breadfruit is concerned, as it is usually consumed as a vegetable. Therefore, lower the reducing sugars, better is the shelf life. Breadfruit packed in unventilated polyethylene bags recorded the lowest value of 2.33 per cent after five days of ambient storage which is significantly different from the other treatments. All the other treatments were on par, with the highest value observed in control sample (3.07%).

Similar results were obtained when fruits were subjected to refrigerated storage with the treatment T_2 recording a reducing sugar content of 3.41 per cent after nine days of storage and the control 4.24 per cent. The remaining treatments have values ranging between 3.5 to 4.1 (Table 3b).

4.1.3.4 Vitamin C

Vitamin C content showed a decreasing trend in all the treatments from an initial level of 18.85mg/100g of fruit with the advancement of the storage period. T_2 recorded the highest value of 18.31mg/100g after five days of storage under room temperature. The values of T_1, T_3 and T_6 for the same period were on par (Table4a). Similar were the results obtained under low temperature, with the highest vitamin C content in T_2 during the entire period of storage with a value of

Table 4a. Vitamin C and crude fibre of breadfruit under different ambient storage techniques.

Treatments	Vitamin C (mg/100 g)			Crude fibre (%)		
	0 DAS	3 DAS	5 DAS	0 DAS	3 DAS	5 DAS
T_1	18.85	18.18^{ab}	18.08^{a}	5.95	5.10	4.41
T_2	18.85	18.53^{a}	18.31^{a}	5.95	4.79	4.24
T_3	18.85	17.82^{abc}	17.72^{a}	5.95	4.47	4.33
T_4	18.85	17.03^{cd}	17.45^{ab}	5.95	4.79	4.33
T_5	18.85	17.58^{bcd}	17.42^{ab}	5.95	4.78	4.08
T_6	18.85	17.97^{abc}	17.85^{a}	5.95	4.47	4.16
T_7	18.85	17.97^{abc}	17.49^{ab}	5.95	4.72	4.22
T_8	18.85	16.57^{d}	16.21^{b}	5.95	4.63	4.13

The values represent means of 3 replications

The values having different superscripts differ significantly at 5% level

Table 4b. Vitamin C and crude fibre of breadfruit under different refrigerated storage techniques

Treatments	Vitamin C (mg/100 g)				Crude fibre (%)			
	0 DAS	3 DAS	7 DAS	9 DAS	0 DAS	3 DAS	7 DAS	9 DAS
T_1	18.85	18.59^{abc}	17.61^{b}	17.05^{ab}	5.95	5.70^{b}	5.64^{a}	5.02^{a}
T_2	18.85	18.57^{abc}	17.99^{a}	17.42^{a}	5.95	5.40^{c}	5.32^{b}	5.00^{b}
T_3	18.85	18.07^{cd}	17.89^{a}	17.45^{a}	5.95	5.80^{a}	5.28^{b}	4.95^{c}
T_4	18.85	18.11^{cd}	17.54^{b}	17.09^{ab}	5.95	5.42^{c}	5.13^{c}	4.77^{e}
T_5	18.85	17.75^{de}	17.04^{c}	16.63^{b}	5.95	5.70^{b}	5.02^{d}	4.82^{d}
T_6	18.85	17.44^{bc}	17.37^{b}	17.35^{a}	5.95	5.69^{b}	4.99^{d}	4.67^{g}
T_7	18.85	18.50^{abc}	17.98^{a}	17.14^{ab}	5.95	5.28^{d}	4.91^{e}	4.73^{f}
T_8	18.85	17.25^{c}	16.70^{d}	15.91^{c}	5.95	5.31^{d}	4.88^{e}	4.62^{h}

The values represent means of 3 replications

The values having different superscripts differ significantly at 5% level

17.42 mg per 100 g on the ninth day. Minimum value of 15.91 mg per 100 g was recorded in control (Table 4b).

4.1.3.5 Crude fibre

The crude fibre content showed a decreasing trend with the advancement of storage period both under ambient and refrigerated temperatures, with the maximum value in T_1, when fruits were wrapped in cling film (4.41%) under room temperature and 5.02 per cent for the same treatment after nine days under refrigeration (Table 4a and 4b). The lowest values were observed in the control samples both under ambient and refrigerated storage as 4.13 per cent and 4.62 per cent after five and nine days of storage respectively.

4.2 Storage of minimally processed breadfruit slices

Minimally processed vegetables are products that have attributes of convenience and fresh like quality. An attempt has been made to store peeled and sliced breadfruit pieces under different packages and storage techniques. The results are presented in Tables 5 to 11.

4.2.1 Storage of minimally processed breadfruit under ambient conditions

Data on changes in chemical parameters in minimally processed breadfruit stored under ambient conditions is given in Table 5.

4.2.1.1 Starch

Starch content shows a gradual reduction with the advancement of storage time irrespective of treatments but with a variation in the rate of reduction, with minimum reduction recorded for samples packed with vacuum (59.08%) and maximum reduction in samples packed with in package fumigant (T_3) (57.75%) and in T_1 (57.87%) when pieces steeped in 1500ppm SO_2 solution after one week in storage.

4.2.1.2 Total sugars

Accompanying the fall in the starch content an increase in the total sugars was also observed during the period of storage. Treatments T_1 and T_3 recorded the maximum of 8.12 per cent and 8.22 per cent respectively and the lowest was seen in T_2 (7.27%) which was superior to all other treatments as lower the total sugar content better is the result.

4.2.1.3 Reducing sugars

After eight days of storage, it was seen that the treatments T_2, T_4 and T_5 were on par with respect to the reducing sugars. Among these T_5 was superior with a low value of 2.44 per cent. Maximum reducing sugars was observed in T_3 (3.16%) when lower is the reducing sugars better is the eating quality of breadfruit pieces as vegetable.

4.2.1.4 Vitamin C

A gradual reduction in the vitamin C content of the product in all the treatments was recorded. Treatment T_5 was found to be superior ($P < 0.05$) to all other treatments after eight days of storage under ambient temperatures (15.1mg/100g).

Table 5. Starch, Total sugars, Reducing sugars, Vitamin C and Crude fibre of minimally processed breadfruit pieces, under different ambient storage techniques.

Treatments	Starch (%)			Total sugars (%)			Reducing sugar (%)			Vitamin C (mg/100 g)			Crude fibre (%)		
	2 DAS	5 DAS	8 DAS	2 DAS	5 DAS	8 DAS	2 DAS	5 DAS	8 DAS	2 DAS	5 DAS	8 DAS	2 DAS	5 DAS	8 DAS
T_1	62.82^{c}	60.69^{c}	57.87^{d}	5.79^{b}	6.87^{c}	8.12^{c}	1.32	2.06^{c}	2.88^{b}	15.62^{a}	14.76^{d}	14.67^{c}	4.71^{a}	4.54^{bc}	4.30^{b}
T_2	64.24^{a}	61.73^{a}	58.28^{a}	5.45^{a}	6.22^{a}	7.57^{b}	1.08	1.82^{a}	2.52^{b}	15.36^{b}	15.04^{c}	15.00^{b}	4.63^{b}	4.61^{ab}	4.20^{c}
T_3	63.06^{b}	60.54^{c}	57.75^{d}	6.05^{c}	6.93^{c}	8.22^{c}	1.25	2.01^{c}	3.16^{c}	15.38^{b}	15.29^{a}	15.08^{b}	4.62^{b}	4.54^{c}	4.25^{bc}
T_4	64.27^{a}	61.47^{b}	58.65^{b}	5.43^{a}	6.19^{a}	7.27^{a}	1.13	1.82^{a}	2.49^{a}	15.17^{b}	15.03^{c}	14.74^{c}	4.70^{a}	4.61^{ab}	4.37^{a}
T_5	64.20^{a}	61.42^{b}	59.08^{a}	5.67^{b}	6.40^{b}	7.72^{b}	1.16	1.88^{b}	2.44^{a}	15.27^{b}	15.12^{b}	15.10^{a}	4.71^{a}	4.64^{a}	4.39^{a}

The values represent means of 3 replications

The values with different superscripts differ significantly at 5 % level

4.2.1.5 Crude fibre

Crude fibre content was found to exhibit a declining trend during the eight days of storage at ambient temperature. Slices packed with vacuum (T_5) and these packed with N_2 gas (T_4) proved to be superior to other treatments, recording crude fibre contents of 4.39 per cent and 4.37 per cent respectively, while minimum was in T_2 (4.20%).

4.2.2 Refrigerated storage

Changes in the chemical constituents of the product as influenced by various treatments under refrigerated storage are given in Table 6.

4.2.2.1 Starch

Treatments T_1 and T_3 were terminated before attaining four weeks storage due to the deterioration in quality. However treatment T_2, T_4 and T_5 could be stored up to four weeks, of which least starch content was noted in T_4 (59.34%) which was significantly different from T_2 and T_5 ($P < 0.05$). Higher the starch content, better is the life.

4.2.2.2 Total sugars

After four weeks of refrigerated storage, the treatment T_2 was found to be superior to all other treatments recording the lowest value of 6.54 per cent. The highest total sugar content was in T_4 (7.26%), which is not a desired quality.

4.2.2.3 Reducing sugars

A trend similar to that of total sugars was exhibited by the reducing sugars also. The minimum value was recorded in T_2 (2.73%) and maximum was in T_4 (3.01%).

Table 6. Starch, Total sugars, Reducing sugars, Vitamin C and Crude fibre of minimally processed breadfruit pieces, under different refrigerated storage techniques.

Treatments	Starch (%)		Total sugars (%)		Reducing sugars (%)		Vitamin C (mg/100 g)		Crude fibre (%)	
	2 WAS	4 WAS	2 WAS	4 WAS	2 WAS	4 WAS	2 WAS	4 WAS	2 WAS	4 WAS
T_1	62.20^{b}	-	6.53^{b}	-	2.86^{b}	-	15.64^{b}	-	4.40^{ab}	-
T_2	64.83^{a}	60.35^{a}	5.78^{a}	6.54^{a}	1.80^{a}	2.73	16.17^{a}	16.10	4.56^{a}	4.14
T_3	60.46^{c}	-	6.64^{b}	-	3.21^{c}	-	15.72^{b}	-	4.29^{b}	-
T_4	65.48^{a}	59.34^{b}	5.70^{a}	7.26^{b}	1.75^{a}	3.01	16.24^{a}	15.76	4.43^{ab}	4.33
T_5	65.55^{a}	60.49^{a}	5.83^{a}	6.68^{ab}	1.75^{a}	2.86	16.43^{a}	16.12	4.40^{ab}	4.18

The values represent means of 3 replications
The values with different superscripts differ significantly at 5 % level
- denotes the treatments discarded due to quality deterioration

4.2.2.4 Vitamin C

Among the treatments remained up to four weeks, all the treatments irrespective of storage temperature showed vitamin C content on par with each other ranging between 15.76 per cent to 16.12 per cent.

4.2.2.5 Crude fibre

Crude fibre content was shown to be decreasing with storage time. Maximum crude fibre was recordd in T_4 (4.33%) after four weeks storage whereas least value was noted for T_2 (4.14%) after the same period. Deterioration in quality after 2 weeks was recorded in case of T_1 and T_3.

4.2.3 Frozen storage

The tabulated results for changes in chemical constituents in minimally processed slices kept under frozen storage is given in Table 7.

4.2.3.1 Starch

Irrespective of the treatments, the starch content registered a decreasing trend from first to fourth month of storage. After four months of storage, T_5 recorded the least value of starch (50.23%) and the highest value of 58.44 per cent was shown by T_4. T_1 and T_2 did not have a storage life beyond two months, since quality, deterioration was noticed, these treatments were terminated after two months of storage.

4.2.3.2 Total sugars

Concomitant to the decrease in starch content an increase in total sugar content was observed in all the treatments during the entire period of storage.

Table 7. Starch, Total sugars, Reducing sugars, Vitamin C and Crude fibre of minimally processed breadfruit pieces, under different frozen storage techniques.

Treat-ments	Starch (%)				Total sugars (%)				Reducing sugar (%)				Vitamin C (mg/100 g)				Crude fibre (%)			
	1 MAS	2 MAS	3 MAS	4 MAS	1 MAS	2 MAS	3 MAS	4 MAS	1 MAS	2 MAS	3 MAS	4 MAS	1 MAS	2 MAS	3 MAS	4 MAS	1 MAS	2 MAS	3 MAS	4 MAS
T_1	62.09^{c}	58.56^{b}	-	-	6.78^{b}	8.48^{c}	-	-	2.19^{b}	3.21^{c}	-	-	14.46^{c}	14.49^{d}	-	-	4.71^{a}	4.07	-	-
T_2	63.76^{a}	61.35^{a}	60.42^{a}	58.35	5.58^{a}	6.60^{a}	8.41^{a}	9.32^{a}	1.32^{a}	2.19^{a}	3.27^{a}	3.71	14.55^{c}	14.50^{b}	14.49^{b}	14.49	4.34^{bc}	4.27	4.06^{b}	4.07
T_3	60.73^{d}	57.27^{c}	-	-	6.48^{b}	8.39^{c}	-	-	2.37^{b}	3.51^{d}	-	-	14.67^{c}	14.27^{b}	-	-	4.18^{c}	4.05	-	-
T_4	62.92^{b}	61.45^{a}	60.29^{a}	58.44	5.66^{a}	7.24^{b}	8.69^{b}	9.49^{a}	1.31^{a}	2.46^{b}	3.49^{ab}	3.60	15.53^{a}	15.40^{a}	15.40^{a}	15.33	4.53^{ab}	4.13	4.18^{ab}	4.16
T_5	63.63^{ab}	61.63^{a}	59.82^{b}	58.23	5.45^{a}	7.28^{b}	8.40^{a}	10.08^{b}	1.41^{a}	2.50^{b}	3.76^{b}	3.84	15.21^{b}	15.00^{a}	14.80^{b}	14.74	4.52^{ab}	4.35	4.21^{ab}	4.19

The values represent means of 3 replications
The values with different superscripts differ significantly at 5 % level
- denotes the treatments discarded due to quality deterioration

Treatments T_2 and T_4 showed lower values of 9.32 per cent and 9.49 per cent respectively while T_5 recorded a value of 10.08 per cent which was significantly higher than that of the other two treatments.

4.2.3.3 Reducing sugars

Similar trend to that of total sugars was observed in case of reducing sugars also during the storage. However there was no significant difference between the treatments T_2, T_4 and T_5 at the end of four months of storage whose values ranged between 3.60 per cent to 3.84 per cent.

4.2.3.4 Vitamin C

With the advancement of storage period, a decline in the content of vitamin C was noticed in all the treatments. T_4, pieces packed with N_2 gas was found to have better retention of vitamin C (15.4mg/100g) at the end of three months of storage with T_2 recording the least value (14.49%). No significant difference was noticed among the treatments after the fourth month of storage.

4.2.3.5 Crude fibre

From the first to fourth month of storage, a decrease in crude fibre content was observed in all treatments. No significant difference between the treatments in terms of crude fibre content was noticed at the end of four months of storage.

4.2.4 Residual SO_2

The residual SO_2 of samples steeped in 1500ppm SO_2 and packed with 0.5g KMS were analysed.

Table 8 shows that maximum residual SO_2 was in the samples steeped in 1500ppm SO_2 irrespective of whether they were stored under ambient, refrigerated or frozen temperatures, which was significantly different from those packed with 0.5g KMS +0.3 per cent citric acid ($p < 0.05$).

Table 8. Residual SO_2 in minimally processed breadfruit slices

Treatments	Ambient (days)			Refrigerated (weeks)	Frozen (months)	
	2	5	8	2	1	2
Steeped in 1500 ppm SO_2	161.80^a	144^a	126.03^a	149.28^a	108.45^a	75.0^a
Packed with 0.5 g KMS + 0.3% Citric acid	117.1^b	87.21^b	71.0^b	77.05^b	68.10^b	37.05^b

The values represent means of 3 replications
The value with different superscripts differ significantly at 5% level

4.2.5 Sensory evaluation

Sensory qualities of the minimally processed breadfruit slices kept in ambient, refrigerated and frozen temperatures was carried out by Kruskal - Wallis One way Anova (Tables 9 to 11).

In the samples stored at ambient temperatures, all the panelists significantly rated T_4 above the other treatments for overall acceptability.

For the refrigerated samples also, the highest rank for quality attributes like colour, texture, flavour and overall acceptability was for T_4.

In the case of frozen samples, colour, flavour and overall acceptability was highest for T_2, while for texture, T_4 was found to have higher score.

Table 9. Sensory evaluation of minimally processed (ambient) product

Treatment	Colour	Texture	Flavour	Overall appearance
T_1	7.5	5.00	3.5	6.25
T_2	7.0	6.50	6.25	7.25
T_3	5.5	4.25	4.00	5.20
T_4	7.0	7.25	5.75	7.50
T_5	7.25	7.0	6.25	7.45
Kruskal Wallis H (5%)	15.36*	18.83*	19.23*	18.51*

* Values differed significantly at 5% level

Table 10. Sensory evaluation of minimally processed (refrigerated) product

Treatment	Colour	Texture	Flavour	Overall appearance
T_1	4.50	2.75	3.50	4.00
T_2	6.00	6.00	6.75	6.50
T_3	2.25	2.50	2.25	3.50
T_4	6.00	7.25	7.25	7.25
T_5	5.75	6.50	6.00	6.75
Kruskal Wallis H (5%)	15.3615*	18.8250*	19.2306*	18.513*

* Values differed significantly at 5% level

Table 11. Sensory evaluation of minimally processed (frozen) product

Treatment	Colour	Texture	Flavour	Overall appearance
T_1	6.25	6.00	6.25	6.00
T_2	7.75	8.00	8.50	8.25
T_3	5.75	6.50	5.50	5.25
T_4	7.50	8.50	8.25	7.75
T_5	7.75	7.75	8.00	7.75
Kruskal Wallis H (5%)	7.814*	8.305*	9.623*	10.140*

* Values differed significantly at 5% level

4.3 Dehydration and subsequent packaging studies

Combinations of different drying methods and different pre-treatments and packaging were tried for the quality improvement in dehydration for better colour retention, lesser shrinkage, faster reconstitution and for better storage life.. The results are tabulated and presented in tables 12 to 22.

4.3.1 Dehydration ratio, shrinkage ratio, reconstitution ratio and extend of discolouration due to drying

The effect of different combinations of drying methods and pre-treatments on the dehydration ratio, shrinkage ratio and reconstitution ratio for breadfruit are presented in Table 12.

4.3.1.1 Dehydration ratio

Significant difference in the dehydration ratio was observed both between pre-treatments and between methods of drying ($P<0.05$) with microwave oven drying being the best method when compared to other methods of drying like mechanical and sun drying. Comparing the dehydration ratio between various pre-treatments, the best was in blanched pieces which were treated with 0.3 per cent citric acid and 1500ppm SO_2 for five minutes prior to drying which was statistically superior to other pre-treatments. Among the combinations, the above said pre-treatment along with microwave oven drying was found to be the best combination (3.81).

4.3.1.2 Shrinkage ratio

The highest value for shrinkage ratio was noted for the samples dried in microwave oven after subjecting it to the pre-treatment involving blanching in water with 0.3 per cent citric acid and 1500ppm SO_2 at 90°C for five minutes (0.67). Least value for shrinkage ratio was for sun dried samples after blanching in water at 90°C for five minutes (0.33). This was on par with the samples dried under sun after blanching in water with 0.3 per cent citric acid and also with samples blanched in water and mechanically dried.

4.3.1.3 Reconstitution ratio

Among the different methods of drying microwave oven drying was found to be superior to other methods of drying as samples dried in microwave oven after blanching in plain water as well as blanching in water with 0.3 per cent citric acid + 1500ppm SO_2 recorded high values of 4.83 and 4.77 respectively which were on par. Sun drying was found to be an inferior method of drying irrespective of the pre-treatments applied.

4.3.1.4 Extend of discolouration due to drying

Samples subjected to sun drying in all the three pre-treated samples turned brown, so also the mechanically dried samples after blanching in plain water. Light brown colour was noticed in samples subjected to mechanical drying after blanching in water with 0.3 per cent citric acid and in water having 0.3 per cent citric acid + 1500ppm SO_2. In case of microwave oven dried samples, samples

Table 12. Dehydration ratio, shrinkage ratio, reconstitution ratio and extend of discolouration due to drying of breadfruit pieces dried under different techniques

Treatment	Dehydration ratio	Shrinkage ratio	Reconstitution ratio	Extend of dicolouration due to drying
90°C water for 5 minutes (SD)	6.65 [a]	0.33 [d]	4.14 [d]	Brown
90°C water for 5 minutes (MD)	4.32 [f]	0.37 [d]	4.47 [c]	Brown
90°C water for 5 minutes (MW)	4.00 [h]	0.55 [b]	4.83 [a]	Light brown
90°C water + 0.3% citric acid for 5 minutes (SD)	5.12 [b]	0.33 [d]	4.10 [d]	Brown
90°C water + 0.3% citric acid for 5 minutes (MD)	4.44 [e]	0.43 [c]	4.42 [c]	Light brown
90°C water + 0.3% citric acid for 5 minutes (MW)	4.53 [d]	0.53 [v]	4.63 [b]	Creamy yellow
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (SD)	4.84 [c]	0.38 [cd]	4.15 [d]	Brown
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (MD)	4.17 [g]	0.55 [b]	4.56 [b]	Light brown
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (MW)	3.81 [I]	0.67 [a]	4.77 [a]	Creamy yellow

The values represent means of 3 replications
The value with different superscripts differ significantly at 5% level

did not turn brown but a creamy yellow colour was noticed under both the pre-treatments except for the sample subjected to blanching in water.

4.3.2 Drying rate, shrinkage rate and reconstitution rate

4.3.2.1 Drying rate

Drying rate with respect to pre-treatments under each method of drying was studied separately and are presented in Table 13 and Figures 1 to 3.

Sun drying

On comparing the drying rate between various pre-treatments followed by sun drying, reduction in weight was highest in case of T_1 i.e., samples blanched in water at 90°C for five minutes (9.91%) after 12 hours of drying. This was significantly different from the other two pre-treatments ($P<0.05$) in which T_2 recorded a value of 10.14 per cent and T_3 10.30 per cent after drying under sun for 12 hours (Fig. 1).

Mechanical drying

Drying rate under mechanical drying revealed that samples blanched in water and then mechanically dried showed most rapid drying rate, where moisture was brought down below 10 per cent within ten hours of drying (9.93%) which was significantly different from the drying rate of other two pretreated samples at 5 per cent levels (10.39% and 10.63% respectively) (Fig. 2).

Microwave oven drying

On comparing the drying rate between the three pre-treatments followed by drying in microwave oven, rapid weight reduction was noticed in samples

Table 13. Drying rate of breadfruit dried under different techniques

Treatments	Sun drying (hours)				Mechanical drying (hours)				Microwave oven drying (minutes)				
	2	4	8	12	2	6	8	10	20	40	60	80	90
90°C water for 5 minutes	60.48^{a}	35.57^{a}	22.52^{c}	9.91^{c}	63.80^{a}	24.08^{a}	14.36^{c}	9.93^{c}	68.77^{b}	41.11^{c}	25.27^{c}	11.16^{d}	9.93^{c}
90°C water + 0.3% citric acid for 5 minutes	51.67^{c}	32.35^{b}	25.60^{b}	10.14^{b}	55.18^{c}	24.18^{ab}	14.56^{b}	10.39^{b}	65.48^{c}	46.86^{b}	25.92^{b}	12.64^{b}	10.45^{b}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes	58.32^{b}	35.63^{a}	27.14^{a}	10.30^{a}	60.45^{b}	26.46^{a}	16.30^{a}	10.63^{a}	77.84^{a}	49.78^{a}	29.16^{a}	12.93^{a}	10.73^{a}

The values represent means of 3 replications
The value with different superscripts differ significantly at 5% level

Fig. 1. Drying curve of sun dried breadfruit under various pre-treatments

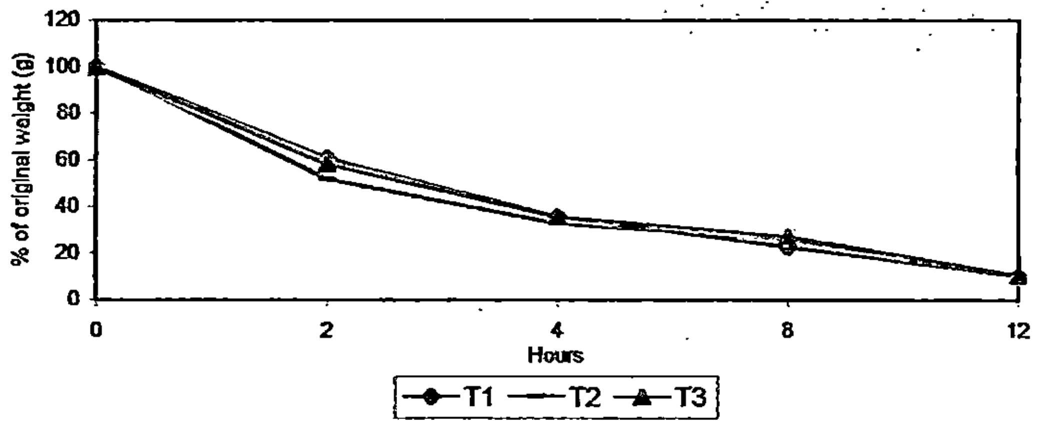


Fig. 2. Drying curve of mechanically dried breadfruit under various pre-treatments

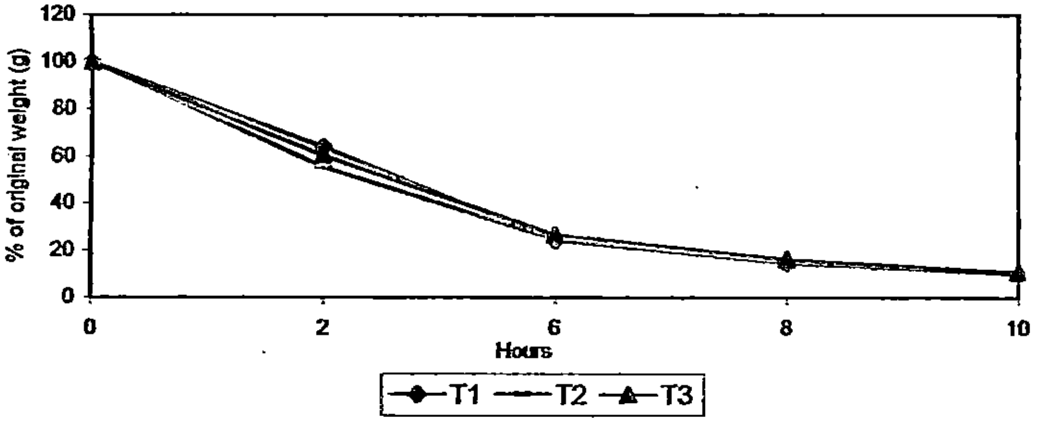
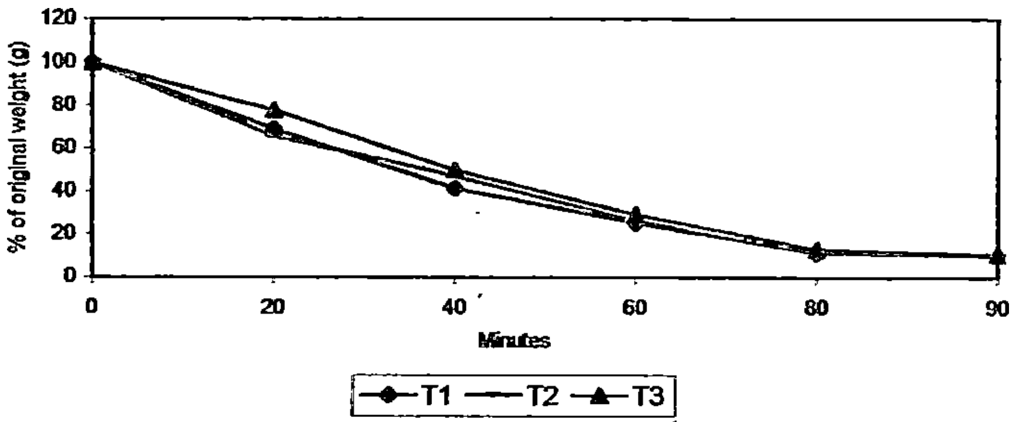


Fig. 3. Drying curve of microwave oven dried breadfruit under various pre-treatments



pretreated by blanching alone, which was significantly different from other two pre-treatments after 90 minutes of drying (9.93%). Weight reduction was minimum for samples blanched in water with 0.3 per cent citric acid + 1500ppm SO_2 (10.731%) (Fig. 3).

4.3.2.2 Shrinkage rate

Shrinkage rate with respect to pre-treatments under each method of drying was studied separately and presented in Table 14 and Figures 4 to 6.

Sun drying

Rate of percentage shrinkage of breadfruit pieces after various pre-treatments followed by sun drying is given in Fig. 4. It was seen that maximum shrinkage (73.29%) was noticed in samples blanched in water prior to drying which was significantly different ($P<0.05$) from the other two pre-treatments. The best pre-treatment exhibiting minimum shrinkage was the one in which samples were blanched in water containing 0.3 per cent citric acid + 1500ppm SO_2 with a value of 68.67 per cent after sun drying for 12 hours.

Mechanical drying

Observation on percent shrinkage of breadfruit pieces during mechanical drying after different pre-treatments revealed that after ten hours of drying, samples subjected to water blanching for five minutes recorded maximum value of 75.53 per cent. No significant difference was noticed among the other two pre-treatments which showed values of 70.71 per cent and 70.32 per cent which

Table 14. Shrinkage rate of breadfruit dried under different techniques

Treatments	Sun drying (hours)				Mechanical drying (hours)				Microwave oven drying (minutes)				
	2	4	8	12	2	6	8	10	20	40	60	80	90
90°C water for 5 minutes	42.81^{a}	55.57^{a}	68.13^{a}	73.29^{a}	28.15^{c}	63.09^{a}	64.29^{b}	75.53^{a}	30.86^{a}	48.63^{c}	60.16^{c}	74.86^{a}	76.63^{a}
90°C water + 0.3% citric acid for 5 minutes	38.12^{c}	51.39^{b}	67.56^{b}	72.55^{b}	29.41^{b}	64.53^{b}	67.43^{a}	70.71^{b}	30.20^{b}	52.46^{b}	62.24^{b}	72.18^{b}	74.09^{b}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes	41.81^{b}	50.49^{c}	63.15^{c}	68.67^{c}	30.39^{a}	60.71^{c}	61.09^{c}	70.32^{b}	29.34^{c}	56.23^{a}	64.30^{a}	70.25^{c}	72.42^{c}

The values represent means of 3 replications
The value with different superscripts differ significantly at 5% level

Fig. 4. Shrinkage curve of sun dried breadfruit under various pre-treatments

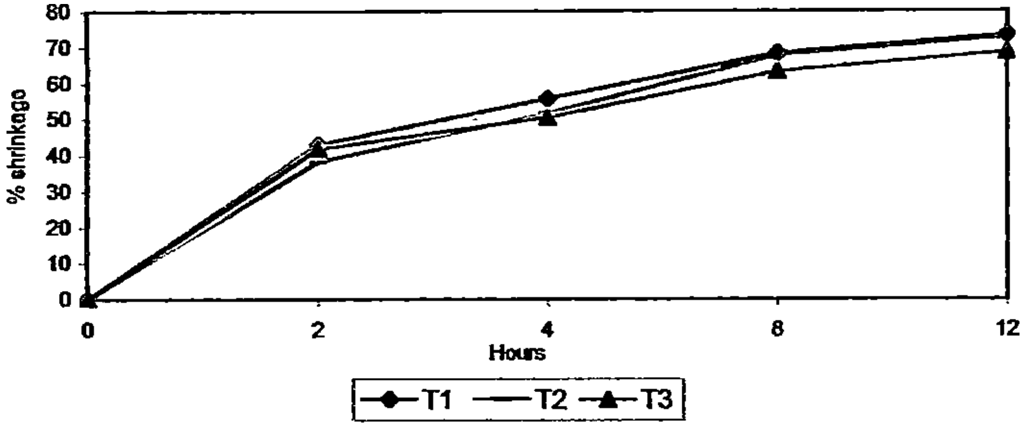


Fig. 5. Shrinkage curve of mechanically dried breadfruit under various pre-treatments

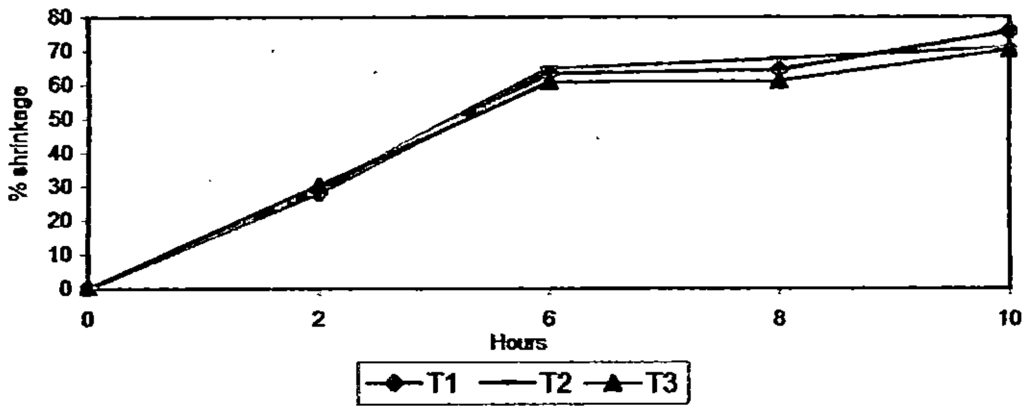
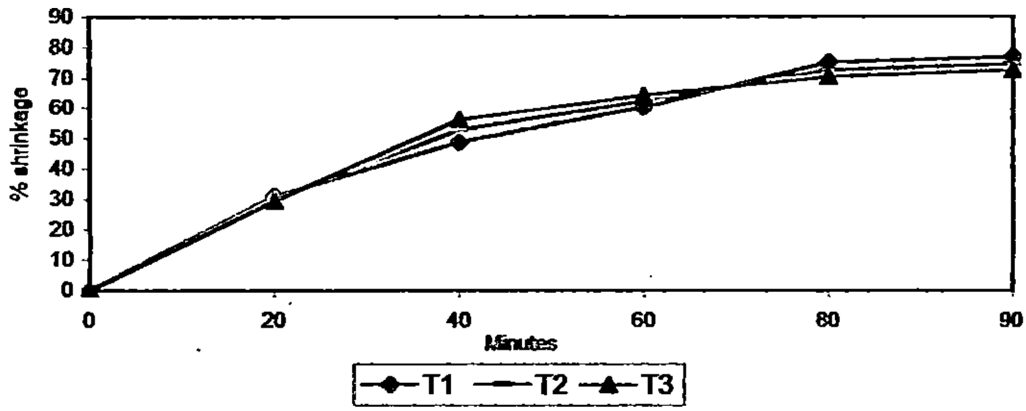


Fig. 6. Shrinkage curve of microwave oven dried breadfruit under various pre-treatments



were on par and differed significantly ($P<0.05$) with water blanched samples (Fig 5).

Microwave oven drying

Regarding the shrinkage rate of samples subjected to drying in microwave oven after different pre-treatments, it was noted that minimum shrinkage percentage was recorded for samples blanched in water with 0.3 per cent citric acid and 1500 ppm SO_2 (74.42%) which proved to be significantly different from the other pretreatments ($P<0.05$) (Fig. 6).

4.3.2.3 Reconstitution rate

Sun drying

The pattern of reconstitution of sun dried breadfruit samples after various pre-treatments are shown in Figure 7. The rate of reconstitution was very fast in samples dried after blanching in water with 0.3 per cent citric acid + 1500 ppm SO_2 (324.10%) where reconstituion was achieved in 60 minutes whereas in the other two pre-treatments it took 90 minutes to complete reconstitution.

Mechanical drying

When mechanically dried, samples dried after blanching in water containing 0.3 per cent citric acid + 1500ppm SO_2 showed the fastest reconstitution in 60 minutes (341.28%). Samples subjected to the other two pre-treatments, i.e., blanching in water and blanching in water with 0.3 per cent citric acid took 90 and 75 minutes respectively (Fig. 8).

Table 15. Reconstitution rate of breadfruit dried under different techniques

Treatments	Minutes				
	15	30	60	75	90
90°C water for 5 minutes (SD)	121.33 [h]	249.18 [g]	292.19 [g]	311.17 [c]	311.23
90°C water + 0.3% citric acid for 5 minutes (SD)	122.17 [g]	268.41 [e]	298.43 [f]	310.23 [d]	315.56
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (SD)	122.53 [g]	262.41 [f]	324.10 [e]	-	-
90°C water for 5 minutes (MD)	138.33 [f]	262.41 [f]	326.67 [e]	344.30 [a]	378.24
90°C water + 0.3% citric acid for 5 minutes (MD)	176.49 [e]	201.18 [h]	286.14 [h]	342.20 [b]	-
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (MD)	268.32 [d]	308.52 [d]	341.43 [c]	-	-
90°C water for five minutes (MW)	277.07 [d]	334.51 [d]	354.29 [b]	-	-
90°C water + 0.3% citric acid for 5 minutes (MW)	295.45 [c]	351.42 [c]	341.43 [c]	-	-
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (MW)	340.56 [a]	357.29 [a]	368.28 [a]	-	-

Values represent means of 3 replication
Values with different superscripts differ significantly at 5% level
- denotes samples reconstituted completely within an hour

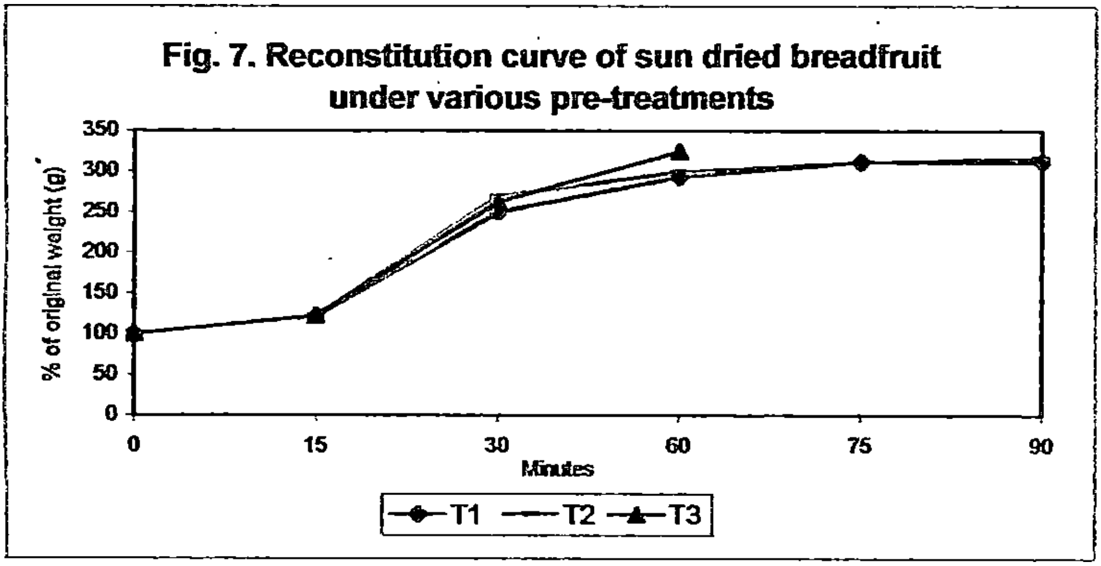


Fig. 7. Reconstitution curve of sun dried breadfruit under various pre-treatments
% of original weight (g)
350
300
250
200
150
100
50
0
0
15
30
60
75
90
Minutes
T1
T2
T3

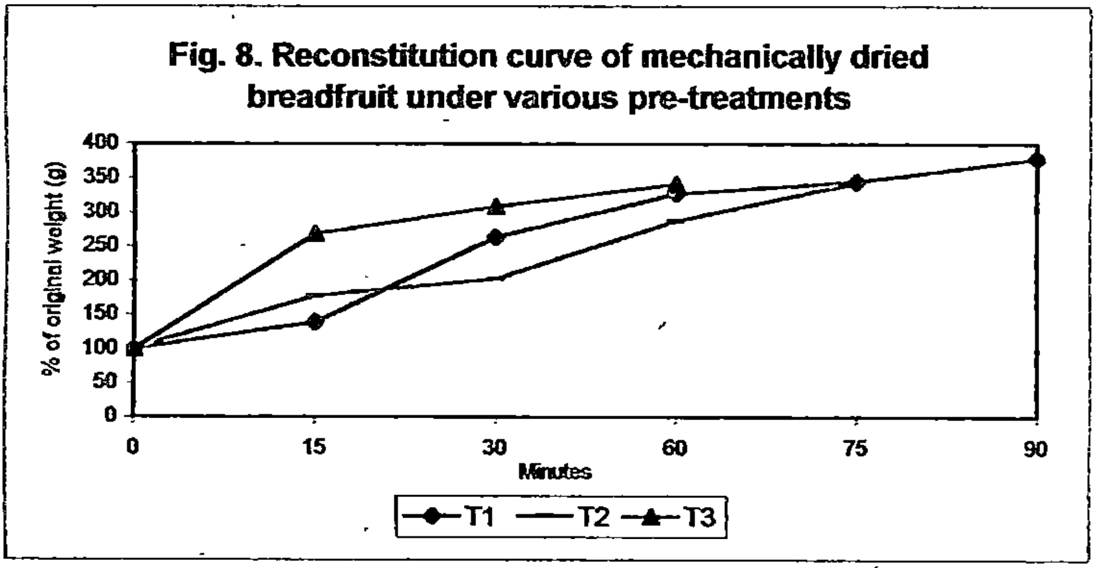


Fig. 8. Reconstitution curve of mechanically dried breadfruit under various pre-treatments
% of original weight (g)
400
350
300
250
200
150
100
50
0
0
15
30
60
75
90
Minutes
T1
T2
T3

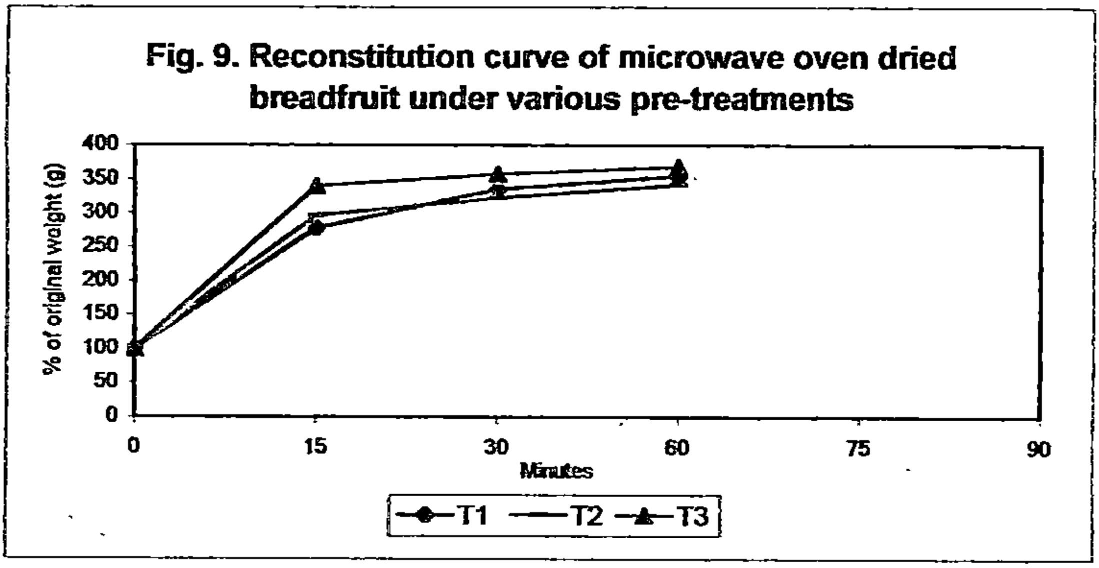


Fig. 9. Reconstitution curve of microwave oven dried breadfruit under various pre-treatments
% of original weight (g)
400
350
300
250
200
150
100
50
0
0
15
30
60
75
90
Minutes
T1
T2
T3

Microwave oven drying

Similar to other methods of drying, in microwave oven drying also, blanched samples treated with 0.3 per cent citric acid + 1500ppm SO_2 showed maximum reconstitution at the end of 60 minutes (368.28%). All treatments differed significantly at 5 per cent level with samples blanched with water + 0.3 per cent citric acid showing minimum reconstitution (341.43%) (Fig. 9).

4.3.3 Moisture pick up

Moisture pick up of dried breadfruit packaged in PE and PP separately during storage were analysed for a period of four months under ambient conditions and presented in Table 16. Comparing the moisture pick up between the type of packaging material used, throughout the period of storage, no significant difference was observed. But between methods of drying, moisture pick up was always high in sun dried samples and it was least in microwave oven dried and they differed significantly during the period of storage. The trend was found to be erratic between the various pre-treatments, during the storage period.

4.3.4 Chemical attributes

4.3.4.1 Starch

There was a gradual decline in the starch content from first to fourth month of storage at ambient conditions. Microwave oven dried samples showed the least reduction followed by mechanical and sun dried samples and they differed significantly ($P < 0.05$). Among the different pre-treatments, samples blanched in water with 0.3 per cent citric acid + 1500ppm KMS recorded higher values except

Table 16 . Percentage moisture pick up of dried breadfruit samples during storage under ambient conditions with different drying techniques and packages

Treatments	Months									
	0		1		2		3		4	
	PE	PP	PE	PP	PE	PP	PE	PP	PE	PP
90°C water for 5 minutes (SD)	10.13	9.91	5.77^{a}	4.84^{c}	6.62^{a}	4.83^{c}	6.62^{b}	4.82^{e}	7.44^{a}	6.65^{b}
90°C water + 0.3% citric acid for 5 minutes (SD)	9.92	9.93	4.89^{c}	3.64^{d}	4.88^{d}	4.52^{e}	5.76^{c}	5.45^{d}	5.80^{d}	5.47^{c}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (SD)	9.85	10.03	4.53^{d}	2.75^{h}	5.42^{b}	4.72^{d}	7.23^{a}	7.70^{a}	-	-
90°C water for 5 minutes (MD)	9.41	9.72	4.01^{e}	5.01^{d}	4.02^{f}	5.81^{b}	4.80^{e}	5.83^{c}	4.82^{f}	6.69^{b}
90°C water + 0.3% citric acid for 5 minutes (MD)	9.85	9.83	3.92^{f}	6.03^{a}	4.66^{e}	6.02^{a}	5.80^{c}	7.07^{b}	6.91^{b}	7.08^{a}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (MD)	9.31	9.32	3.45^{h}	3.15^{f}	3.83^{g}	4.04^{f}	4.72^{f}	4.55^{f}	6.24^{c}	4.88^{d}
90°C water for five minutes (MW)	9.73	9.93	2.82^{i}	2.82^{g}	2.82^{i}	2.82^{h}	3.75^{g}	3.83^{g}	4.59^{g}	4.65^{e}
90°C water + 0.3% citric acid for 5 minutes (MW)	10.22	9.83	3.71^{g}	3.23^{e}	3.71^{h}	3.24^{g}	-	3.23^{h}	-	3.99^{f}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (MW)	9.62	9.72	5.36^{b}	1.72^{i}	5.33^{c}	1.74^{i}	5.33^{d}	1.74^{i}	5.72^{e}	2.68^{g}

The values represent means of 3 replications
The values having different superscripts differ significantly at 5% level
- denotes the treatments discarded due to quality deterioration

in case of sun dried samples where the life of the product was only for three months. Among the different packaging materials, no significant difference was observed between packaging methods viz., PP or PE during storage (Table 17).

4.3.4.2 Total sugars

An increasing trend in total sugar content was observed during the storage period. Samples dried in microwave oven after blanching in water with 0.3% citric acid and 1500ppm KMS was found to be of better quality since they recorded least values for total sugars (5.86% and 5.72% respectively) for both PE and PP packed samples. Sun drying was found to be the inferior among drying techniques (Table 18).

4.3.4.3 Reducing sugars

Effects of treatments and methods of drying on reducing sugars during storage of breadfruit pieces packaged in PE and PP were studied and reported in Table 19. Among various drying methods, microwave oven drying was found to be statistically superior ($P < 0.05$) to the other two methods. Among the different pre-treatments blanching in water with 0.3 per cent citric acid + 1500ppm KMS was found to be better in all methods of drying. Packaging material did not have any significant difference during the four months of storage.

4.3.4.4 Vitamin C

Maximum retention of ascorbic acid was recorded in microwave oven dried samples, under all the three different pre-treatments, followed by mechanical

Table 17. Starch content of dried breadfruit during storage under ambient conditions with different drying techniques and packages in percentage

Treatments	Months							
	1		2		3		4	
	PE	PP	PE	PP	PE	PP	PE	PP
90°C water for 5 minutes (SD)	63.37^{c}	63.45^{e}	62.64^{cd}	62.64^{g}	60.60^{d}	62.24^{d}	60.43^{c}	61.23^{b}
90°C water + 0.3% citric acid for 5 minutes (SD)	63.38^{c}	63.49^{de}	63.10^{b}	62.72^{f}	61.81^{c}	62.13^{e}	60.22^{d}	60.27^{d}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (SD)	63.53^{bc}	63.54^{cde}	62.98^{b}	63.04^{cd}	62.12^{b}	62.47^{b}	-	-
90°C water for 5 minutes (MD)	63.72^{b}	63.73^{b}	62.40^{e}	63.04^{cd}	61.75^{c}	62.25^{d}	60.57^{b}	61.14^{c}
90°C water + 0.3% citric acid for 5 minutes (MD)	63.57^{bc}	63.74^{b}	62.74^{c}	62.96^{de}	61.51^{d}	62.15^{e}	60.18^{d}	61.26^{b}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (MD)	63.70^{b}	64.38^{a}	63.68^{c}	63.20^{b}	61.17^{e}	62.44^{b}	60.04^{e}	61.17^{c}
90°C water for five minutes (MW)	63.63^{bc}	63.61^{bcd}	62.55^{d}	63.02^{cd}	61.24^{e}	62.33^{c}	61.17^{a}	61.11^{c}
90°C water + 0.3% citric acid for 5 minutes (MW)	63.46^{bc}	63.67^{bc}	63.03^{b}	62.94^{e}	-	61.82^{f}	-	61.15^{c}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (MW)	64.49^{a}	64.51^{a}	63.39^{a}	63.90^{a}	62.36^{a}	62.56^{a}	61.14^{a}	61.20^{b}

The values represent means of 3 replications
The values having different superscripts differ significantly at 5% level
- denotes the treatments discarded due to quality deterioration

Table 18. Total sugar of dried breadfruit during storage under ambient conditions with different drying techniques and packages in percentage

Treatments	Months							
	1		2		3		4	
	PE	PP	PE	PP	PE	PP	PE	PP
90°C water for 5 minutes (SD)	5.08^{ab}	5.15^{b}	5.26^{d}	5.35^{c}	5.37^{ef}	5.48^{d}	6.11^{e}	6.09^{d}
90°C water + 0.3% citric acid for 5 minutes (SD)	5.26^{e}	5.27^{c}	5.24^{cd}	5.36^{c}	5.30^{cd}	5.49^{d}	6.22^{f}	6.16^{d}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (SD)	5.07^{ab}	5.13^{b}	5.19^{bc}	5.24^{b}	5.43^{g}	5.48^{d}	-	-
90°C water for 5 minutes (MD)	5.16^{cd}	5.14^{b}	5.24^{cd}	5.24^{b}	5.36^{ef}	5.42^{c}	5.92^{cd}	5.92^{c}
90°C water + 0.3% citric acid for 5 minutes (MD)	5.21^{de}	5.16^{b}	5.28^{d}	5.22^{b}	5.41^{fg}	5.36^{b}	5.91^{bcd}	5.75^{b}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (MD)	5.13^{bc}	5.16^{b}	5.23^{cd}	5.21^{b}	5.35^{de}	5.36^{b}	5.89^{bc}	5.89^{c}
90°C water for five minutes (MW)	5.06^{a}	5.22^{c}	5.16^{b}	5.31^{c}	5.27^{bc}	5.34^{b}	5.96^{d}	5.92^{c}
90°C water + 0.3% citric acid for 5 minutes (MW)	5.16^{cd}	5.13^{b}	5.37^{e}	5.25^{b}	-	5.36^{b}	-	5.85^{c}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (MW)	5.10^{b}	5.03^{a}	5.05^{a}	5.06^{b}	5.22^{b}	5.23^{a}	5.86^{b}	5.72^{b}

The values represent means of 3 replications
The values having different superscripts differ significantly at 5% level
- denotes the treatments discarded due to quality deterioration

Table 19. Reducing sugar of dried breadfruit during storage under ambient conditions with different drying techniques and packages in percentage

Treatments	Months							
	1		2		3		4	
	PE	PP	PE	PP	PE	PP	PE	PP
90°C water for 5 minutes (SD)	1.15^{e}	1.12^{c}	1.28^{d}	1.22^{c}	1.29^{cd}	1.35^{bc}	1.95^{c}	2.06^{e}
90°C water + 0.3% citric acid for 5 minutes (SD)	1.13^{de}	1.21^{d}	1.30^{d}	1.28^{d}	1.36^{e}	1.35^{bc}	2.01^{d}	1.98^{d}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (SD)	1.12^{cde}	1.04^{ab}	1.15^{b}	1.16^{b}	1.27^{bc}	1.33^{bc}	-	-
90°C water for 5 minutes (MD)	1.14^{e}	1.13^{c}	1.22^{c}	1.20^{bc}	1.36^{e}	1.37^{c}	1.81^{b}	1.81^{c}
90°C water + 0.3% citric acid for 5 minutes (MD)	1.13^{de}	1.12^{c}	1.17^{b}	1.17^{bc}	1.25^{bc}	1.34^{bc}	1.96^{cd}	1.82^{c}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (MD)	1.08^{bcd}	1.09^{b}	1.17^{b}	1.22^{c}	1.34^{de}	1.31^{bc}	1.82^{b}	1.84^{c}
90°C water for five minutes (MW)	1.04^{ab}	1.02^{a}	1.16^{b}	1.17^{bc}	1.35^{de}	1.36^{c}	1.84^{b}	1.83^{c}
90°C water + 0.3% citric acid for 5 minutes (MW)	1.04^{ab}	1.03^{ab}	1.17^{b}	1.16^{bc}	-	1.31^{bc}	-	1.70^{b}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (MW)	1.02^{a}	1.06^{ab}	1.07^{a}	1.14^{b}	1.22^{b}	1.16^{a}	1.83^{b}	1.75^{b}

The values represent means of 3 replications
The values having different superscripts differ significantly at 5% level
- denotes the treatments discarded due to quality deterioration

Table 20. Vitamin C of dried breadfruit during storage under ambient conditions with different drying techniques and packages (mg/100g)

Treatments	Months							
	1		2		3		4	
	PE	PP	PE	PP	PE	PP	PE	PP
90°C water for 5 minutes (SD)	11.83^{cd}	11.87^{e}	11.82^{d}	11.86^{c}	11.77^{e}	11.82^{c}	11.73^{c}	11.75^{d}
90°C water + 0.3% citric acid for 5 minutes (SD)	11.85^{cd}	11.93^{de}	11.83^{d}	11.86^{de}	11.72^{ef}	11.83^{c}	11.70^{c}	11.79^{c}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (SD)	11.94^{c}	12.02^{c}	11.90^{c}	11.98^{c}	11.90^{c}	11.93^{c}	-	-
90°C water for 5 minutes (MD)	11.92^{c}	11.97^{cd}	11.92^{e}	11.90^{de}	11.87^{d}	11.90^{c}	11.83^{b}	11.86^{b}
90°C water + 0.3% citric acid for 5 minutes (MD)	11.92^{c}	11.95^{de}	11.91^{c}	11.92^{d}	11.83^{d}	11.83^{c}	11.72^{c}	11.72^{c}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (MD)	11.72^{d}	11.73^{f}	11.68^{e}	11.68^{f}	11.67^{f}	11.67^{d}	11.65^{d}	11.63^{d}
90°C water for five minutes (MW)	12.41^{ab}	12.33^{b}	12.40^{a}	12.33^{b}	12.35^{b}	12.30^{b}	12.32^{a}	12.26^{a}
90°C water + 0.3% citric acid for 5 minutes (MW)	12.53^{a}	12.52^{a}	12.46^{a}	12.44^{a}	-	12.43^{a}	-	12.42^{a}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (MW)	12.35^{b}	12.37^{b}	12.35^{b}	12.32^{b}	12.32^{b}	12.24^{b}	12.33^{a}	12.22^{a}

The values represent means of 3 replications
The values having different superscripts differ significantly at 5% level
- denotes the treatments discarded due to quality deterioration

Table 21. Crude fibre of dried breadfruit during storage under ambient conditions with different drying techniques and packages in percentage

Treatments	Months							
	1		2		3		4	
	PE	PP	PE	PP	PE	PP	PE	PP
90°C water for 5 minutes (SD)	4.17^{f}	4.53^{a}	4.25^{e}	4.54^{a}	4.47^{a}	4.55^{b}	4.45^{a}	4.45^{a}
90°C water + 0.3% citric acid for 5 minutes (SD)	4.33^{d}	4.32^{bc}	4.33^{d}	4.32^{b}	4.26^{c}	4.29^{cde}	4.22^{bc}	4.22^{cde}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (SD)	4.37^{d}	4.34^{b}	4.36^{cd}	4.37^{b}	4.40^{b}	4.35^{c}	-	-
90°C water for 5 minutes (MD)	4.53^{cd}	4.32^{bc}	4.53^{a}	4.24^{c}	4.49^{a}	4.25^{e}	4.47^{a}	4.22^{e}
90°C water + 0.3% citric acid for 5 minutes (MD)	4.43^{a}	4.36^{b}	4.40^{bc}	4.36^{b}	4.37^{b}	4.33^{cd}	4.34^{ab}	4.32^{c}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (MD)	4.40^{bc}	4.16^{d}	4.38^{cd}	4.16^{d}	4.40^{b}	4.24^{e}	4.46^{a}	4.24^{e}
90°C water for five minutes (MW)	4.15^{f}	4.27^{c}	4.15^{f}	4.27^{c}	4.17^{d}	4.28^{de}	4.17^{c}	4.31^{cd}
90°C water + 0.3% citric acid for 5 minutes (MW)	4.24^{e}	4.18^{d}	4.24^{e}	4.22^{c}	-	4.26^{c}	-	4.26^{de}
90°C water + 0.3% citric acid + 1500 ppm SO_2 for 5 minutes (MW)	4.46^{b}	4.50^{a}	4.46^{b}	4.54^{a}	4.26^{c}	4.54^{a}	4.25^{bc}	4.43^{ab}

The values represent means of 3 replications
The values having different superscripts differ significantly at 5% level
- denotes the treatments discarded due to quality deterioration

and sun drying. All the three pre-treatments were found to record values on par in both microwave oven drying and sun drying and significant difference ($P < 0.05$) was noticed, among the pre-treatments only in case of mechanical drying, where water blanching resulted in better ascorbic acid retention (Table 20).

4.3.4.5 Crude fibre

Crude fibre content recorded an increasing trend throughout the storage period. After four months of storage, maximum crude fibre content was recorded in samples subjected to water blanching and then sun dried. Minimum values were recorded in case of mechanically dried samples, where the pre-treatments of water blanching and blanching in water with 0.3 per cent citric acid + 1500ppm SO_2 were on par (Table 21).

4.3.4.6 Residual SO_2

The residual SO_2 of samples pre-treated with KMS + citric acid and dried under different methods were analysed after reconstitution in boiling water for five minutes.

Table 22 showed that the maximum residual SO_2 was in the microwave oven dried samples throughout the storage period and was significantly different from other samples ($P < 0.05$). The samples subjected to sun and mechanical drying also differed significantly among each other with higher values in mechanically dried samples.

Table 22. Residual SO_2 of KMS treated dried breadfruit during storage under ambient conditions (ppm)

Treatments	Months			
	1	2	3	4
T_{13}	91.35	77.27 ^{e}	60.43 ^{e}	-
T_{14}	90.61	74.37 ^{f}	59.29 ^{f}	-
T_{15}	108.24	89.69 ^{d}	84.07 ^{b}	71.26 ^{b}
T_{16}	102.97	93.71 ^{c}	84.63 ^{b}	59.21 ^{d}
T_{17}	114.83	100.33 ^{a}	88.87 ^{a}	70.09 ^{b}
T_{18}	128.77	98.45 ^{b}	82.96 ^{c}	73.15 ^{a}

Values represent means of 3 replications
Values with different superscripts differ significantly at 5% level
- denotes samples reconstituted completely within an hour

Discussion

DISCUSSION

Breadfruit, a tropical fruit crop originated in the Indo-Malayan archipelago is an important staple crop in that area. The fruit is starchy and the mature unripe fruit alone is consumed as a vegetable in the same way as tubers and root crops. Nutritionally, it is as good as the root and tuber crops and in certain cases it is superior to them in terms of vitamins and minerals. It is not consumed in the real sense as a fruit where ripening is a pre-requisite for consumption, instead it is eaten as a vegetable in the pre-ripe stage. Therefore the ultimate goal of preservation of breadfruit is to arrest or prolong the ripening phenomenon so as to extend the shelf life of the whole fruit. Hence various pre-treatments and packaging techniques were employed to extend the shelf life of both whole fruit as well as minimally processed slices. An attempt has also been made to store the slices in a dehydrated form. The results of these experiments are discussed in this chapter.

5.1 Storage of fresh breadfruit

Breadfruit, like other tropical fruits softens and deteriorates rapidly under ambient tropical conditions of high temperature and humidity (24-31°C; RH > 65%). This softening in breadfruit occurs within two or three days of harvest. Maharaj and Sankat (1989) noted that at ambient temperatures (28°C) breadfruit undergoes browning of the skin during ripening and attributed this to the normal degradative changes associated with ripening. Submerging fruits in water, a traditional method of breadfruit storage had helped in maintaining the bright green colour of the skin under ambient conditions suggesting that water loss may be one of the reasons for browning (Thompson *et al.*, 1974). Water loss from epidermal cells could cause cell damage such as membrane leakage which in turn brings soluble phenolics into contact with polyphenol oxidase, causing browning and ultimately cell death. By reducing the rate of transpiration freshness can be maintained, hence moisture proof films can be employed for such purposes. Accordingly various films with varying ventilation have been tried to minimize the rate of transpiration and respiration with the idea to extend the shelf life of the fruit both under ambient and refrigerated temperatures.

5.1.1 Physiological loss in weight

In the present study, the treatments, viz, wrapping the fruit in cling film and packaging fruits in unventilated PE film were recorded as the most superior treatments in all the quality attributes, by which successful storage of the fruit for five days at ambient temperature and seven days under refrigeration were made possible (Plate 4).

During the process of respiration and transpiration, there occurs water loss from the fruit which reduces the fresh appeal. Physiological loss in weight (PLW) is the loss in saleable weight and hence has to be minimized. Minimizing the water loss from the produce involves lowering the capacity of surrounding air to take up additional water, that is, the vapour pressure difference between the produce and air surrounding it is to be minimized. This is the principle behind providing a pre-package to the fresh fruit.

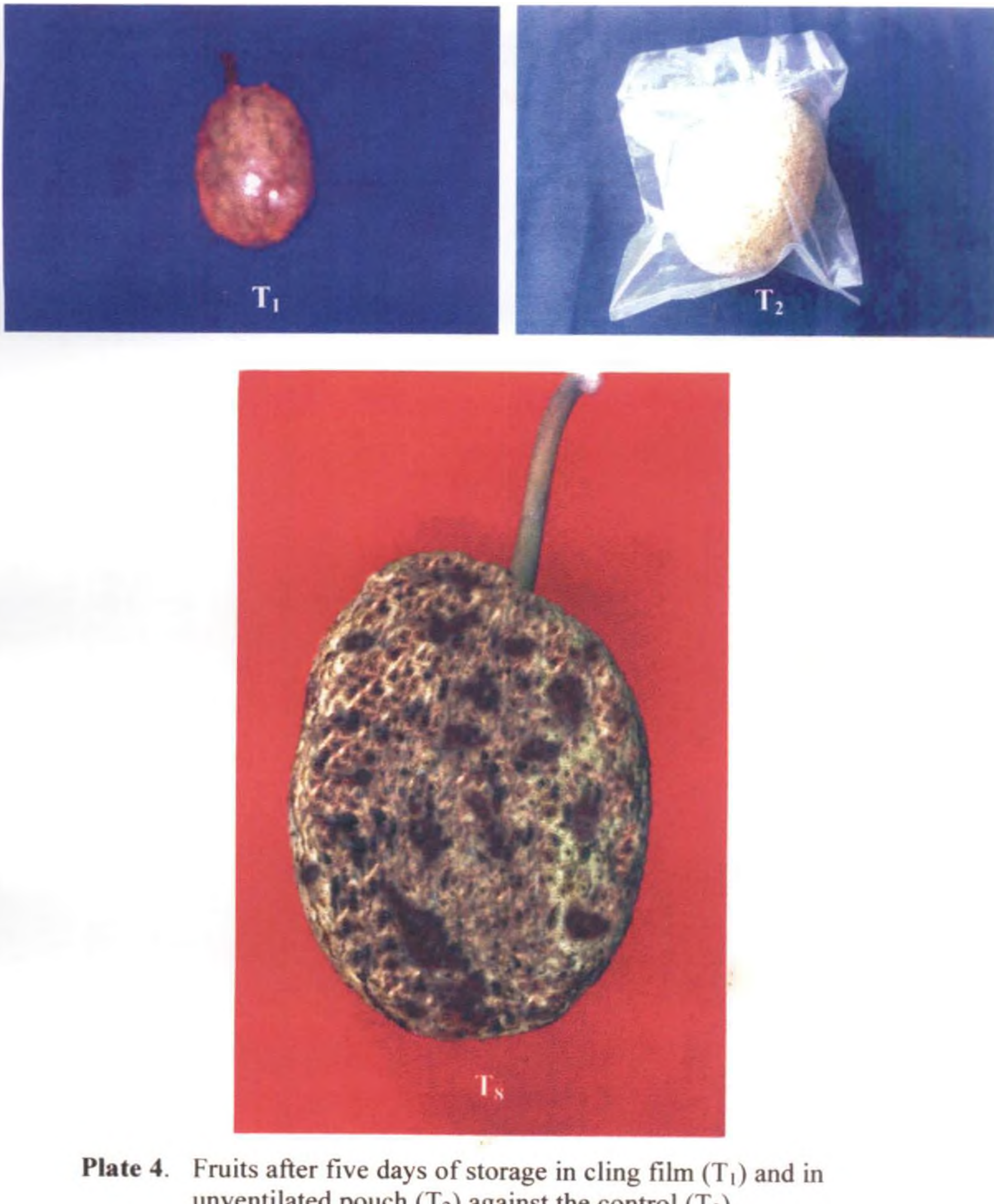


Plate 4. Fruits after five days of storage in cling film (T_1) and in unventilated pouch (T_2) against the control (T_8)

In modified atmosphere packaging, utilization of oxygen for respiration produces respiratory heat and water, resulting in high humidity around the commodity.

PE without ventilation recorded the least PLW up to the end of storage. The PE acts as a controlled condition and it reduced the weight loss and extended the shelf life. The low PLW is due to the high humidity created within the packages by the respiring fruits. The PLW was highest in unwrapped fruits. These results are in confirmity with the finding of Thompson *et al.* (1974), Marriott *et al.* (1979) and Worrell and Carrington (1997). The high PLW recorded in unwrapped fruits as well as in fruits wrapped in newspaper, showed that it is due to the higher rate of water vapour transmission. This resulted in higher transpiration rate and thus low relative humidity within the immediate surroundings of the stored materials.

Storage under low temperature is suggested as a good method for restricting deterioration of breadfruit since refrigerated storage has been shown to extend the post harvest life of the produce (Kader, 1992). Storing fruits under refrigerated conditions significantly reduced weight loss compared to storage under ambient conditions (Sankat and Maharaj, 1993).

The results of the present study showed that under low temperature (7 ± 2°C) the treatments, viz., wrapping fruits with cling film and packaging it in unventilated PE bags were found to impart maximum shelf life. The shelf life was found to be more than that of ambient storage under the same treatments. This is because the relative humidity under refrigerated system is higher compared to ambient conditions, hence the vapour pressure difference is reduced, resulting in lower rate of moisture loss from the commodity. Besides lower temperature has reduced the rate of respiration and hence the relative increase in the shelf life. Hence the results here indicate that packaging fresh breadfruit in unventilated PE bags or wrapping the fruits individually with cling film, both under ambient condition or refrigerated storage is superior to all other treatments, which is in conformity with the findings of Thompson *et al.* (1974), Marriott *et al.* (1979), Sankat and Maharaj (1993) and Worrell and Carrington (1997).

5.1.2 Firmness

Firmness showed a significant and continued decrease reflecting the rapid softening of pulp resulting from biochemical processes such as hydrolysis of starch and accumulation of soluble solids (Barnell, 1941). In the present study, fruits packaged in unventilated PE bags exhibited a significant delay in softening compared to unwrapped fruits. This behaviour is attributed to the modified atmosphere conditions created by packaging and the subsequent delay in the ripening and softening rates (Sankat and Maharaj, 1993).

Polyethylene film is partly permeable to O_2 and CO_2 and the proportion of these two gases surrounding the fruit wrapped in PE would be changed during storage as a result of respiration and diffusion. Softening due to ripening in plantains is slower at high humidity compared to low humidity, and since 100 per cent humidity would rapidly be created around breadfruits in PE bags owing to its high respiration rate, which could have contributed to the effect (Thompson *et al.*, 1974).

Fruits packed in ventilated PE bags lost fruit firmness within a significantly shorter time compared to those in unventilated PE bags. This is in conformity with the results in guava where firmness of stored fruits were found to be inversely proportional to the levels of ventilation tried (Venketesha and Reddy, 1994). The control fruits softened within the least time, due to hydrolysis of starch, hemicellulose and cellulose during ripening by way of high rate of respiration.

The reduction in fruit firmness was found to be less in refrigerated storage compared to ambient storage. Here also, fruits wrapped in unventilated PE bags recorded maximum firmness after seven days of storage. The increase in fruit softening beyond this period may be due to the climacteric rise in the respiration rate. This is in accordance with the reports of Marriott *et al.* (1979) and Passam *et al.* (1981).

5.1.3 Starch

The starch content of the fruit was found to decrease during the storage period. The decrease is due to conversion of starch to sugars, a phenomenon observed in banana, apple and many other tropical and subtropical fruits (Spencer, 1965). Breadfruit exhibits a typical climacteric respiratory pattern with very high O_2 consumption and CO_2 production even at 20°C (Biale and Barcus, 1970). In the present study, starch breakdown was found to be least in those fruits wrapped in unventilated PE bags and the modified atmosphere in the pack with high concentration of CO_2 must have slowed down the rate of starch breakdown. This is in corroboration with the results of Yamashita *et al.* (1997) in mangoes.

5.1.4 Sugars

Total and reducing sugars were found to increase throughout the storage period irrespective of treatments. This may be due to rapid synthesis of sugars from precursors like starch, which is largely dependent on the storage temperature and time. So the storage life was five days at ambient temperature and nine days under refrigeration. This was in confirmity with the report of Adewusi *et al.* (1995) who reported that breakdown of carbohydrates to sugars as an indicator of fruit deterioration in breadfruit was highest when fruits were stored under room temperature and less when stored under water or in a refrigerator.

5.1.5 Vitamin C

The vitamin C content exhibited a decreasing trend with ripening of the fruit in all the treatments. This has been reported by Graham and DeBravo (1981) who explains that it may be due to possible conversion of vitamin C to other compounds or enzymatic degradation. The decrease may be due to the influence of comparatively higher oxygen content in the atmosphere (Singh *et al.*, 1970) coupled with cellular disorganization (Harris and Karmas, 1977) which disintegrates the ascorbic acid.

5.1.6 Crude fibre

Crude fibre content was found to decrease with advancement of storage period. The decrease in crude fibre content as the fruit matures probably reflects the degradation of hemicellulose and other polysaccharide material during ripening (Graham and DeBravo, 1981).

5.2 Storage of minimally processed breadfruit slices

Minimally processed fruits and vegetables can be defined as those fruits and vegetables that have been cleaned, peeled, cut, sliced and packaged by any means, short of killing the tissues. Minimal processing is done for live plant tissues after washing, and giving sanitation or preservation treatment and then giving it proper packaging, so that chances for contamination by microbes is reduced. Thus it is possible to retain the product in a near to fresh form and yet for a longer period. It also has the added advantage of being in 'ready to cook' form. In the present study, breadfruit after peeling and slicing had been subjected to blanching in water for three minutes and then given various treatments with the purpose of having an extended shelf life compared to fresh fruit.

Discolouration occurs at the cut surface of fruits and vegetables as a result of disruption of compartmentation that occurs when cells are broken allowing substrates and oxidases to come into contact. Wounding also induces synthesis of some enzymes involved in browning reactions or substrate biosynthesis (Rolle and Chism, 1987). Oxidative browning at cut surface is a limiting factor in storage of many minimally processed fruits. In the present study, the breadfruit after slicing were blanched at 90°C for three minutes, for inactivating the enzymes causing browning.

Among the different treatments tried for extension of life of minimally processed breadfruit slices at ambient temperature, modified atmosphere packaging of the product proved to be better.

Modified atmosphere packaging (MAP) is the method for extending the shelf life of perishable and semi perishable food products by altering the relative proportions of atmospheric gases that surround the food (Barmor, 1987; Day, 1992; Wade, 1980). This differs from controlled atmosphere storage (CAS) where the storage atmosphere is different from normal atmosphere by precise adjustment of the component gases to specific concentrations and maintaining it throughout the storage period (Debney *et al.*, 1980). So in MAP, there is no means to control precisely the atmospheric components at a specific concentration once a package has been hermetically sealed (Day, 1990). MAP can help in extension of storage life by retarding deteriorative changes and providing better retention of commodity. The altered atmosphere can slow down the physiological metabolism; retard the process of ageing, reduce chances of enzymatic reactions and provide better retention of cellular components like sugars, organic acids etc. (Baxter and Waters, 1991 and Kaji *et al.*, 1993). In the present study, minimally processed breadfruit slices packaged with nitrogen gas (T_4) was found to have better sensory qualities in terms of colour, texture and flavour, compared to other treatments at ambient temperature. Packaging the slices with N_2 and with CO_2 were found to be nutritionally superior to the other treatments.

MAP coupled with low temperature storage is found to impart longer shelf life to minimally processed product. Quality deterioration can be retarded by decreasing the temperature of plant tissue and this can enhance the quality and shelf life by at least three to five fold or more (Wills *et al.*, 1989). In the present study, T_2, packaged with CO_2 gas and kept under refrigeration was found to have a shelf life of four weeks as against one week at ambient temperature. The same was the case with T_4 and T_5, packaged with N_2 and vacuum respectively.

Frozen storage of minimally processed breadfruit slices were also done and breadfruit slices packaged in modified atmosphere with CO_2, N_2 and vacuum i.e., T_2, T_4 and T_5 respectively were found to keep without any quality deterioration for four months. This result is in conformity with the findings of Passam *et al.* (1981) who reported that storage life of 12 weeks could be attained for breadfruit pieces subjected to freezing storage in aluminium foil package; the additional life here obtained is due to the cocktail effect of low temperature and modified atmosphere package as explained by Wills *et al.* (1989) (Plate 5).

When fruits are peeled, sliced or diced, oxidation is stimulated and changes in vitamin C can be observed. Blanching with hot water, steam or a combination of the two can cause leaching of minerals and destruction of vitamin C (Woodroof, 1988). Vitamin C losses up to 25 per cent has been reported due to leaching into the water during blanching (Lee *et al.*, 1982). In fruits approximately 17 per cent loss in ascorbic acid has been reported due to blanching. In the present study, during the storage of minimally processed breadfruit slices, a

Plate 5. Minimally processed breadfruit slices packaged in CO_2 (T2) and Vacuum (T5) after four months of frozen storage

slight decrease in starch and vitamin C has been reported, which is in accordance with the above findings. The residual SO_2 concentration was higher in the samples steeped in 1500ppm SO_2 and stored under ambient conditions. The permitted SO_2 levels in 'ready to serve' foods is 70ppm. On cooking the amount of residual SO_2. in the samples is found to reduce to one fifth of the original quantity (Narasimham and John, 1995). In the present study, under all three temperatures of storage the residual SO_2 content was found to be below the maximum permitted level.

5.3 Dehydration and packaging studies

Despite its ease of cultivation in the tropics, breadfruit is underexploited as a food, principally, because of its poor post harvest storage behaviour (Wootton and Tumaali, 1984b). Dehydration is a suitable method for long term storage of the fruit and is comparatively a cheaper method employed on a commercial scale. It involves simple air drying to modern freeze drying methods. Even though freeze drying has several advantages over air drying, it is an expensive technique. Therefore air drying is most commonly employed, when striking a compromise between the quality and the cost.

Drying refers to the removal of water by heat to such a level that biochemical and microbial activities are checked due to reduced water activity in the product.

In the present study, breadfruit slices were subjected to three pre-treatments and three methods of drying and could be stored without deterioration for a period of four months. By drying, the water activity gets reduced to such a level that biochemical and microbial activity are kept at minimum, which was further maintained by providing packaging to the product. The dehydrated product is comparatively hygroscopic, therefore unless stored properly will pick up moisture rapidly and will invite microbial spoilage, thus deteriorating the product. So providing a suitable packaging to dried product is essential.

Blanching is a hot water treatment in which fruits or vegetables are subjected to heating in water or live steam before processing (Kalra, 1990). This is to inactivate the enzymes, to prevent browning in the dried product. Blanching in boiling water for five minutes, helped in obtaining good quality dried breadfruit (Narasimham and John, 1995). In the present study, the samples subjected to blanching for five minutes in hot water (90°C) with 0.3 per cent citric acid and 1500 SO_2 was better in colour and rehydration properties and it also maintained the colour during the entire storage period. Sulphuring or sulphiting is known to prevent the enzyme catalysed oxidative changes, inhibit microbial deterioration and facilitate drying by plasmolysing the cells (Tanga, 1974).

Out of the three drying methods, the breadfruit dried in microwave oven was found to have the best colour, flavour and texture. This is in agreement with the finding of Decareau(1984) who reported that quality of the product dried in microwave oven was superior in terms of colour and texture. This is also due to the lesser time involvement in the microwave oven drying than in the other drying methods.

Mechanically dried breadfruit samples were having better overall appearance compared to sun dried samples. This is supported by Khedhkar and Roy (1989) in mango and Jayaraman *et al.* (1991) in vegetables.

The time taken for drying the blanched samples was 12 hours in sundrying, 10 hours in mechanical drying and only 90 minutes in microwave oven drying. This difference in time for drying can be attributed to the difference in the drying mechanism involved and the instruments used for the drying (Suguna et al, 1995).

Sahni *et al.* (1998) reported that microwave energy is believed to inactivate microbes by the conventional thermal mechanism including potentially irreversible heat denaturation of enzymes, proteins, nucleic acids or other cellular constituents vital to cell metabolism and reproduction resulting in cellular death. However Chipley (1980) proposed that an athermal mechanism of lethal action exists, an effect that can be attributed to the intrinsic nature of microwave, and unrelated to lethality caused by heat; that is how better quality is maintained in the microwave oven dried samples.

Dehydration ratio is an indicator of yield. Yield and quality of the dried product are influenced by factors like initial moisture content, drying, temperature and time, susceptibility of the material to heat damage, pre-drying treatment and moisture content of the finished produce (Kaushal and Sharma, 1995).

In the present study, the highest yield was seen in microwave oven drying followed by mechanical drying and sun drying. The highest yield during microwave oven drying may be due to shorter period of exposure of material to heat damage. This finding is supported by Decareau (1984) who reported that microwave processing resulted in shorter processing time, higher yields and better quality than by conventional drying. The report of Ruello (1984) that fast cooking time of microwaves resulted in the retention of volatile substances which were usually expelled during conventional cooking, further authenticated the result (Plate 6).

Out of the different pre-treatments, highest yield was recorded in samples blanched in water with 0.3 per cent citric acid + 1500ppm SO_2 followed by these blanched in water with 0.3 per cent citric acid and lowest yield was in samples subjected to water blanching. This may be because, the particles of citric acid and KMS might have entered the intercellular spaces of breadfruit thus contributing to the higher weight. The breadfruit pieces lost weight due to blanching, which resulted in lower yield in T_1. The rate of drying was rapid for samples dried after water blanching.

Similar to dehydration ratio, minimum shrinkage was shown by microwave oven dried samples, followed by mechanical and sundrying respectively; this is also due to the duration of heat involvement, more the time of exposure to heat, more will be the textural breakdown; microwave oven drying involved the least time, hence higher shrinkage ratio. This is in agreement with the findings of Rama (1998) in mushrooms.

Plate 6. Dehydrated breadfruit slices after four months storage

Among different pre-treatments, the lowest shrinkage was recorded for samples dried after blanching in water having 0.3 per cent citric acid + 1500 ppm SO_2. Comparing the various methods of drying, microwave oven drying was superior to mechanical and sundrying with respect to rehydration ratio. Better texture retention by microwave oven drying compared to other methods might account for this factor.

The fastest rehydration and highest reconstitution ratio was exhibited by samples microwave oven dried with blanching in water having 0.3 per cent citric acid + 1500 ppm SO_2. The elasticity of cell walls and swelling power of starch, which are important for good rehydration are reduced when heat treatment is prolonged as suggested by Arsdel and Copley (1963); the lower rehydration ratio of sundried samples may be explained by the above statement. The rehydration ratio of sulphited lots was higher than for the other two, probably due to better texture retention in the sulphited lots.

The residual moisture content was maximum in sun dried samples followed by mechanical and microwave oven dried samples. This indicated the efficiency of microwave oven drying in removing maximum moisture in shortest time. A gradual increase in the moisture content was observed during storage in all dried samples irrespective of packaging material used. This is probably because both PE and PP used here are not 100 per cent barrier proof for water vapour transmission. However they are the best available material for the packaging of dried products as suggested by Balasubramanyam (1995). Hence a very slow ingress of moisture can be expected with the advancement storage period; especially when the relative humidity is higher around the storage vicinity.

Processing of fruits by dehydration, freezing etc. result in changes in the composition of the product, which is reflected in the nutritional value. Losses may occur in sugars, acids, vitamin C and minerals. Dehydration can alter the chemical composition of products and change the nutritional qualities to some extend (Young, 1975). Light accelerates lowering of vitamin C content of processed products, the losses are more when clear plastic films are used for packaging (Karlsson, 1988 and Kenny, 1978). During the storage of dehydrated breadfruit slices, in the present study, a gradual reduction in nutritional quality, i.e., starch, vitamin C and increase in sugars were noticed which is in agreement with the above findings.

Summary

SUMMARY

Studies on the shelf life of bread fruit (*Artocarpus altilis* (Park) Fosberg) were carried out in the Department of Processing Technology, College of Horticulture, Vellanikkara, during 2000-01. The main objectives were to develop a simple and cheap storage technique to extend the shelf life of breadfruit under ambient and refrigerated conditions, to store breadfruit slices in a semi processed form so as to make it available during the off season and to keep it in a dehydrated form with suitable pre-treatments and packages, intended to be available almost round the year.

The PLW of bread fruit under both cling film and unventilated polyethylene bags of 250 gauge were lesser than the corresponding controls at both ambient and refrigerated temperatures. The two packaging techniques were found to be equally good with respect to all parameters evaluated viz., starch, total and reducing sugars, ascorbic acid, crude fibre and firmness. The life of the fruit could be extended up to five days and nine days under ambient and refrigerated conditions respectively.

Minimally processed breadfruit slices with modified atmosphere packaging were found to have longer shelf life. In case of ambient storage, the product could be successfully stored without any deterioration in quality when packaged with N_2 gas for a period of eight days. Combining modified atmosphere packaging with low temperature storage imparted longer life to the product. Under refrigeration, the life of the product could be extended up to one month. Frozen

storage of the breadfruit slices, extended the shelf life further to four months when packaged in modified atmosphere with CO_2, N_2 and vacuum.

Under dehydration studies, the samples pre-treated with citric acid + KMS was found to be the best in quality and could be stored for four months. without any quality degradation. Comparing the various drying techniques, microwave oven drying proved to be superior to sun drying and mechanical drying with respect to rehydration ratio. The samples pretreated with citric acid + KMS recorded lowest shrinkage, longer storage and better yield. No significant difference was observed between polypropylene and polyethylene as a packaging material for dried samples during storage.

Microwave oven drying, though resulted in superior quality product is an expensive proposition and hence commercially, mechanical drying could be employed to strike a compromise between quality and cost of production. Dried material is to be packaged in PE or PP films to prevent moisture reabsorption.

References

REFERENCES

Achinewhu, S.C. 1982. The nutritive qualities of plant foods: chemical and nutritional composition of breadfruit (*Artocarpus altilis*) and climbing melon seed. *Nutrition Reports International*. **25**:643-647

Adewusi, S.R.A., Udio, J., Osuntogun, B.A. 1995. Studies on the carbohydrate content of breadfruit (*Artocarpus communis* Forest) from South-Western Nigeria. Starch/Starke **47**(8):289-294

Altman, L.J. and Zito, S.W. 1976. Sterols and triterpenes from the fruit of *Artocarpus altilis*. *Phytochemistry*. **15**:829-830

Arcelay, A. and Graham, H.D. 1984. Chemical evaluation and acceptance of food products containing breadfruit flour. *Caribbean J. Sci.* **20**(1/2):35

Arsdel, W.B.V. and Copley, M.J. 1963. *Food dehydration Vol. I.* The AVI Publishing Company Inc. West Port p.66-82

Balasubrahmanyam, N. 1995. Profile on Food Packaging. Publication of Central Food Technological Research Institute, Mysore p.24-37

Barmor, C.R. 1987. Packaging technology for fresh and minimally processed fruits and vegetables. *J. Food Qual.* **10**:207-217

Barnell, H.R. 1941. Studies in tropical fruits. XI. Carbohydrate metabolism of the banana fat during ripening under tropical conditions. *Ann. Bot.* **5**:217-250

Barrau, J. 1957. Investigation to extend season of breadfruit yield. *South Pac. Comm. Quart. Bull.* **4**(4):20-40

Bates,R.P., Graham, H.D., Mathews, R.F. and Clos, L.R. 1991. Breadfruit chip: Prepration, stability and acceptability. *J. Fd. Sci.* **56**(6):1608-1610

Baxter, L., Waters, Jr. L. 1991. Quality changes in asparagus spears stored in a flow through CA system or in consumer packages. *HortScience* **26**:399-402

Biale, J.B. and Barcus, D.E. 1970. Respiratory patterns in tropical fruits of the Amozon Basin. *Trop. Sci.* **12**:93-104

Bowers,R.D. 1981. Breadfruits: A low energy requirement source of carbohydrate for wet tropics. *Entwicklung Landlicher Raum*, **15**(2):11-13

Brecht, J.K., Sabaa-Srur, A.V.O., Sargent, S.A. and Bender, R.J. 1993. Hypochlorite inhibition of enzymic browning of cut vegetables and fruit. *Acta Hort.* **343**:341-344

Cantwell, M. 1992. Postharvest handling systems: Minimally processed fruits and vegetables. p.277-281. In: Kader, A.A. (ed.) *Postharvest technology of horticultural crops*. 2nd ed. University of California, Oakland Publication 3311.

Chipley, J.R. 1980. Effects of microwave irradiation on microorganisms. *Adv. appl. Microbiol.* **20**:129-145

Chopra, S.L. and Kanwar, S.J. 1978. *Analytical Agricultural Chemistry*. Kalyani Publishers, Ludhiana.

Coenen, J. and Barrau, J. 1961. The breadfruit tree in Micronesia. *South Pac. Bull.* **11**;37-67

Coronel, R.E. 1990. Promising fruit of the Philippines. College of Agriculture. Laguna, Philippines. 379-396

*Correa, A.M.N., Nakamura, T. and Tolmasquim, E. 1970. Study of the properties of breadfruit starch. *Revista Brasileira de Technologia*, **1**:27-31

Cox, P.A. 1980. Two Samoan technologies for breadfruit and banana preservation. *Econ. Bot.* **34**:181-184

CSIR. 1948. *Wealth of India, Vol.2*. Publication and Information Directorate, New Delhi. pp. 123-124

Day, B.P.F. 1990. Modified atmosphere packaging of selected prepared fruit and vegetables. *Processing and Quality of Foods*. (ed. Zenthen P.) Elsevier Science Publishers, Barking, Essen, p.3230-3323

Day, B.P.F. 1992. An update on chilled atmosphere/modified atmosphere vacuum packaging developments in Europe. In: 9th Annual Food '92 conference. The Plastics Institute of America, Fairfield, New Jersey, USA, pp.1-21

Debney, H.G., Blacker, K.J., Reddins, B.J., Watkins, J.B. 1980. Handling and storage practices for fresh fruit and vegetables. Product Manual, Australian United Fresh fruit and vegetable association.

Decareau, R.V. 1984. Microwave in food processing. *Food Tech. Australia* **36**(2):81-86

Gertmenian, D. 1992. Maximum shelf-life is critical in fresh cut marketing. *Produce Business*. Oct. 1992. p.76

Goodman, R.A. 1972. Plants and man in Somoa Pae: Discovery, 25, 12-18

Graham, H.D. and DeBravo, E.N. 1981. Composition of the breadfruit. *J. Food Sci.* **46**:535-539

Harris, R.S. and Karmas, E. 1977. *Nutritional Evaluation of Food Processing.* The AVI Publishing Co., Inc. Westport, Connecticut, p.382

Iwaoka, W., Hagi, Y., Umano, K. and Shibamoto, T. 1994. Volatile chemicals identified in fresh and cooked breadfruit. *J. agric. Food Chem.* **42**:975-976

Jayaraman, K.S., Das Gupta, D.K., Baburao, N. 1991. Quality characteristics of some vegetables dried by direct and indirect sun drying. *Indian Food Packer* **45**(1):16-23

John, P.J. and Narasimham, P. 1998. Shelf life and acceptability of minimally processed breadfruit pieces. *J. Food Sci. Technol.* **35**(1):69-71

Kader, A.A. 1986. Biochemical and physiological basis for effects of controlled and modified atmospheres on fruits and vegetables. *Food Technol.* **40**:99-100, 102-104

Kader, A.A. 1992. Postharvest biology and technology: an overview. In: Kader, A.A. (ed.) *Postharvest Technology of Horticultural Crops.* Publication 3311. University of California, Oakland. 15-20

Kaji, H., Ueno, M., Osajima, Y. 1993. Storage of shredded cabbage under dynamically controlled atmosphere of high oxygen and high carbon dioxide. *Biosci. Biotech Biochem.* **57**:1042-1052

Kalra, C.L. 1990. Blanching of fruits and vegetables. *Indian Food Packer* **44**(5): 3-19

*Kapitsmadi, C.M. 1989. Effect of storage temperature on the post harvest behaviour of four tomato cultivars. *Gartenbauwissenschaft* **54**(2):66-70

Karlsson, E. 1988. Storage life and Quality retention. *Commercial Vegetable Processing* (ed. Luh, B.S. and Woodroof, J.G.) The AVI Publishing Co. Inc. USA pp. 694-707

Kaushal, B.B.L. and Sharma, K.D. 1995. Post harvest technology of mushroom. (In) *Advances in Horticulture Vol.13* (ed. Chadha, K.L. and Sharma, S.R.). Malhotra Publishing House, New Delhi, India p.553-565

Kenny, T.A. 1978. Nutrients are lost from fruits and vegetables between field and table. *Farm Food Res.* **9**:136

Khedhar, D.N., Roy, S.K. 1989. Storage studies in dried and dehydrated raw mango slices. *Acta Hort.* **231**:721-731

Lee, C.V., Massey, R.M. and Van Buren, J.P. 1982. Effect of post harvest handling and processing on vitamin content of peas. *J. Food. Sci.* **47**:961

Loos, P.J., Hood, L.F. and Graham, H.D. 1981. Isolation and characterisation of starch from breadfruit. *Cereal Chem.* **58**:282

Mackenzie, J.B., Mc Knight, R.K. and Lawrence, P. 1964. Breadfruit cultivation practices and benefits in the trust territory of the pacific islands. Office of Agana, Guam. Anthropological Working Papers No.7 and 8, 64

Mathews, R.F., Bates, R.P. and Graham, H.D. 1986. Utilisation of breadfruit in the tropics. *Proceedings of the Inter American Society for Tropical Horticulture.* **30**:83-94

Maharaj, R. and Sankat, C.K. 1989. Storage time/temperture studies on the breadfruit. Caribbean Food Crops Society, 25th Annual Meeting 704-715

Maharaj, R. and Sankat, C.K. 1990. The shelf life of breadfruit stored under ambient and refrigerated conditions. *Acta Horticulturae* **269**:411-424

Marriott, J., Perkins, C. and Been, B.O. 1979. Some factors affecting the storage of fresh breadfruit. *Scientia Horticulturae* **10**:177-181

Narasimham, P. 1990. Breadfruit and jackfruit. (In) *Fruits of tropical and subtropical origin, composition, properties and uses* (eds. Nagy, S., Shaw, P.E. and Wardowski, W.F.). Florida Science Source, INC Lalee Alferd, Florida, U.S.A. 193-259

Narasimham, P., and John, P.J. 1995. Controlled low temperture vacuum dehydration as alternative to freeze drying of diced breadfruit. *J. Fd. Sci. Technol.* **32** (4):305-309

Ocansey, O.B. 1984. Effect of vacuum and atmospheric freeze drying on quality of shrimp, turkey flesh carrot samples. *J. Fd. Sci.* **49**:1457-1461

Ochse, J.J. 1931. *Vegetables of Dutch East Indies.* Published in collaboration with Backhuizen, R.C. Van den Brink, by Holff, G. and Company, Jakarta, Indonesia

Omobuwajo, T.O. nd Wilcox, B.F. 1989. Microbes associated with spoilage of breadfruit. *Tebensmittel Wissenschaft and Technologic* **22**:175-178

Panse, V.G. and Sukhatme, D.V. 1976. *Statistical methods for Agricultural Workers.* Indian Council of Agricultural Research, New Delhi, p.360

Passam, H.C., Maharaj, D.S. and Passam, S. 1981. A note on freezing as a method of storage of breadfruit slices. *Trop. Sci.* **23**:67-74

Pruthi, J.S., Gopalakrishnan, M. and Bhat, A.V. 1978. Studies on the dehydration of tropical paddy straw mushroom (*Volvariella volvacea*) *Indian Food Packer* **32**(2):7-15

Purseglove, J.W. 1968. *Tropical Crops*. London, Longmans. 379-384

Rama, V. 1998. Shelf life of Oyster mushroom. M.Sc. thesis, Kerala Agricultural University, Vellanikkara, Thrissur, India. pp. 95.

*Ramlochan, R. 1991. Transient cooling and storage of breadfruit in refrigerated and controlled atmosphere environment. M.Phil. thesis, University of the West Indies, St. Augustine, Trinidad p. 121

Ranganna, S. 1986. *Manual of Analysis of Fruit and Vegetable Products*. Tata McGraw Hill Publishing Co. Ltd., New Delhi p.2240

Reeve, R.M. 1974. Histological structure and commercial dehydration potential of breadfruit. *Econ. Bot.* **28**:82-96

Roberts - Nkrumah, L. 1993. Breadfruit in the Caribbean - a bicentennial review. *Tropical Fruits Newsletter*. **6**:3-4

Rolle, R.S.. and Chism, G.W. 1987. Physiological consequences of minimally processed fruits and vegetables. *J. Food Qual.* **10**:157-177

Ruello, J.H. 1984. Seafood and microwaves: Some preliminary observations. *Food Technol. Australia* **39**(11):82-86

Sadasivan, S. and Manikam, A. 1992. *Biochemical methods for agricultural sciences*. Wiley Eastern Ltd., New Delhi and TNAU, Coimbatore p.184-186

Sahni, C.K., Khurdiya, D.S., Dalal, M.A. and Maini, S.B. 1998. Microwave processing of foods – potentialities and prospects. *Indian Food Packer* **52**(2):14-20

Sankat, C.K. and Maharaj, R. 1993.Refrigerated storage of the Breadfruit and the Effects of Waxing, Packaging and Storage in Water. *Indian Food Packer.*47(3):47-61

Schlimme, D.V. 1995. Marketing lightly processed fruits and vegetables. *Hort Science* **30**(1):15-17

Shewfelt, R.L. 1987. Quality of minimally processed fruits and vegetables. *J. Food Qual.* **10**:143

Singh, B.N.A., Littlefidd and Salumkhe, D.K. 1970. Effect of chilled atmosphere storage on amino acids, organic acids, sugars and rate of respiration of Lambert sweet cherries. *J. Am. Soc. Hort. Sci.* **95**:458-461

Siriphanich, J. 1993. Minimal processing of tropical fruits. In: Champ, B.R., Highley, E. and Johnson, G.I. (eds.) *Postharvest Handling of Tropical Fruits.* Proc. International Conference at Ching Mai, Thailand 19-23 July, 1993. 127-137

Siegel, S. 1956. *Nonparametric statistics for the behavioural sciences.* McGraw Hill Ltd. p.301

Spencer, M. 1965. Fruit ripening. In *"Plant Biochemistry"*, p.793, Academic Press, New York

Srivastava, M.P. and Tandon, R.N. 1968. Influence of temperature on Botryodiploidia rots of citrus and sapodilla. *Indian Phytopath.* **21**:195-197

Stone, B.C. 1974. The correct botanical name for breadfruit. *Polynesian Soc.* **83**:92-93

Suguna, S., Usha, M., Sreenarayanan, V.V., Raghupathy, R. and Gottandapani, L. 1995. Dehydration of mushroom by sundrying, thin layer drying; fluid bed drying and solar cabinet drying. *J. Food Sci. Technol.* **32**(4):284-288

Suryanathmisae. 1988. Storage of farm products in rural Papua New Guinea. *Agricultural Mechanization in Asia, Africa and Latin America.* **19**:58-64

Tanga, A.Q. 1974. Weight loss in mushroom during canning. *Indian Mushroom Sci.* **1**:225-232

Thomspon, A.K., Been, B.O. and Perkins, C. 1974. Storage of fresh breadfruit. *Trop. Agric.* **51**:407-415

*Tumaalii, F. 1982. Influence of maturation on the composition of breadfruit (*Artocarpus altilis*). M.Sc. thesis, Kensington, NSW. The University of New South Wales. p. 137

Venkatesha, M. and Reddy, T.V. 1994. Use of PE bags to extend the shelf life of guava fruits. *Indian Food Packer* Vol.**48**(5):5-7

*Wade, N.L. 1980. Atmosphere composition as an aid to refrigeration. CSIRO Food Res. Qly. **40**:84-90

Whitney, P.J. 1988. The microbiology of breadfruit and cassava preservation by pit fermentation. *Trop. Sci.* **28**:43-50

Wills, R.B.H., Mc Glasson, W.B., Graham, D., Lee, T.M. and Hall, E.G. 1989. *Postharvest, an introduction to the physiology and handling of fruit and vegetables*. 3rd ed. Van Nestrand Reinbold, New York pp. 84-89

Woodroof, J.G. 1988. *Preparing vegetables for processing commercial vegetable processing* (ed. Luh, B.S. and Woodruf, J.G.) The AVI Publishing Co. Inc., USA p.180-181

Wootton, M. and Tumaalii, F. 1984a. Breadfruit production, utilisation and composition - a review. *Food Technol. Australia* **36**:464-465

Wootton, M. and Tumaalii, F. 1984b. Composition of flours from Samoan breadfruit. *J. Food Sci.* **49**:1396-1400

Worrell, D.B. and Carrington, C.M.S. 1997. Breadfruit. (In) *Postharvest Physiology and Storage of Tropical and Subtropical Fruits* (ed. Mitra, S.K.), CAB. International pp. 347-361

Worrell, D.B., Carrington, C.M.S. and Huber, D.J. 1994. Growth, maturation and ripening of soursop (*Annona muricata* L. fruit). *Sci. Hort.* **57**:7-15

Yamashita, F., Benassi, M.T., Kiecbbusch, T.G. 1997. Shelf life extension of individually film wrapped mangoes. *Trop. Sci.* **37**:249-255

Young, C.T. 1975. Composition and nutritive value of raw and processed fruits. (In) *Commercial fruit processing.* (ed. Woodroof, J.G. and Luh, B.S.) The AVI Publishing Co. Inc., Connecticut. p.539-575

* Originals not seen

SHELF LIFE OF BREADFRUIT
(*Artocarpus altilis* (Park) Fosberg)

By

CHITRA K. PILLAI

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirement for the degree of

Master of Science in Horticulture

Faculty of Agriculture
Kerala Agricultural University

Department of Processing Technology
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR - 680 656
KERALA, INDIA

2001

ABSTRACT

An experiment was conducted in the Department of Processing Technology, College of Horticulture, Vellanikkara during 2000-01 to evolve a simple and cheap technique for storage of fresh breadfruit under ambient and refrigerated conditions and to store it in minimally processed and dehydrated forms for making it available during the off season.

Packaging fresh fruits in unventilated PE pouches as well as wrapping of individual fruits with cling film proved to be beneficial in extending the life up to five days at ambient and for nine days at refrigerated conditions with least deteriorative changes.

Modified atmosphere packaging proved to be beneficial in extending the life of minimally processed breadfruit slices, when coupled with low temperature storage it was even more successful in extending the life as well as quality of the product.

The breadfruit pieces dehydrated after pre-treating with citric acid + KMS showed better colour, lesser shrinkage and higher reconstitution and could be stored for four months without any spoilage, when packed in PP or PE bags after subjecting it to microwave oven drying.