STORAGE STUDIES ON PRESERVATION OF BANANA AND IT'S PRODUCTS

BY
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THESIS

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2000

DECLARATION

I hereby declare that this thesis entitled **"Storage studies on preservation of banana and it's products"** 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, associateship, fellowship, or other similar title of any other University or Society.

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Certified that this thesis entitled **"Storage studies on preservation of banana and it's products"** is a record of research work done independently by Kum. Sindhu Bhaskar under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to her.

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SYMBOLS AND ABREVIATIONS

Agric.	-	Agricultural
ANOVA	-	Analysis of variance
approx.	-	approximately
ASAE	-	American Society of Agricultural Engineers
ASCA	-	Atmolysair System Controlled Atmosphere
CA	-	Controlled Atmosphere
cm	-	centimetres
Co.	-	Company
congr.	-	Congress
Dev.	-	Development
Dept.	-	Department
EMC	-	Equilibrium Moisture Content
Engg.	-	Engineering
ERH	-	Equilibrium Relative Humidity
et al.	-	and others
etc	-	etcetera, and other things
Fig.	-	Figure(s)
h	-	hour(s)
Int.	-	International
ISAE	-	Indian Society of Agricultural Engineers
J.	-	Journal
KCAET	-	Kelappaji College of Agricultural Engineering and Technology
kg	-	kilogram
l	-	litre(s)
LDPE	-	Low Density Polyethylene
lpm	-	litre(s) per minute
Ltd.	-	Limited
m	-	metres
M	-	molar
MAP	-	Modified Atmosphere Packaging
ml	-	milliliter(s)
mm	-	millimeter(s)
min	-	minute
MS	-	Mild Steel
N	-	Normal
NEB	-	Non-Enzymatic Browning
nm	-	nanometre
No.	-	Number
PE	-	Polyethylene
PLW	-	Physiological loss in weight
ppm	-	parts per million
Proc.	-	Proceedings
PVC	-	Poly Vinyl Chloride

Res.	-	Research
RH	-	Relative humidity
RT	-	Room Temperature
Sci.	-	Science
s.	-	second(s)
Soc.	-	Society
Tech.	-	Technology
Trans	-	Transactions
TSS	-	Total soluble solids
Univ.	-	University
var.	-	variety
Viz	-	namely
&	-	and
/	-	bar, per
%	-	per cent
'	-	minute(s)
"	-	second(s)
°Brix	-	Degree Brix
°C	-	degree Celsius

INTRODUCTION

CHAPTER I

INTRODUCTION

Banana (*Musa Paradaisica*) belonging to the family, Musacea and is strictly a tropical plant. There are about 60 varieties of banana grown in India. Only a dozen are of commercial importance. The varieties of banana, which have commercial importance in Kerala are Nendran, Robusta, Poovan, Palayankodan and Kunnan.

The fruits mature in about four months after flowering, but they are usually picked before they mature when about three months old. The matured fruit is 15-25 cm long depending on the variety, mostly elongated and curved having more or less round cross section.

India has emerged as the largest producer of banana at global level by producing 10.41 million tonnes of banana. In India banana contributes to 31 % of the total fruit production. In banana cultivation, Tamil Nadu has the largest area (59050 ha) followed by Maharashtra, Karnataka and Andhra Pradesh as reported by Singh and Uma (1997). Maharashtra tops the production and productivity owing to cultivation of high yielding 'Cavendish Cultivation'. In Kerala banana is cultivated in the entire state and is an integral part of homestead system of farming.

Banana is a vegetable as well as fruit apart from being used for the preparation of various products. It provides a more balanced diet than any other fruit or vegetable. The calorific value is 67-187/100 g. For the vegetable types it will be desirable if greenness could be prolonged without being ripened to the extent possible.

In Kerala the farmers sell the fruit directly to the market during peak season. High fruit yield will be worthwhile only if the fruits reach consumer in sound condition. Banana fruits begin to loose their orchard freshness shortly after they are plucked from the tree. The post harvest losses of banana has been estimated as 12-19%. These losses are due to many factors such as rapid ripening, high respiration and transpiration rates, softening of flesh, microbial spoilage, lack of proper storage facilities, improper handling and damage during long-distance transport. Respiration is considered to be a major catabolic process, which brings about natural ripening, senescence and subsequently deterioration of the fruit in its normal course of time. Further, the bulky nature of the bunch after with loosely packed fingers and soft nature of the fruit create problems in handling. This reduces the earnings of the farmer and makes cultivation of banana nonprofitable. The post harvest losses of banana can be minimized by adoption of modern storage facilities and technologies having special emphasis on proper packaging and conversion of produce into value added products.

Banana chips, puree, figs, soft drinks, powder, jam, confectionary, dehydrated core slices, etc are the main products of banana. Nendran chips, jaggery coated chips and powder are of special mention at present in the Kerala context. Therefore these products are of much importance under this study.

While cooking banana chips, it is important to control frying temperature of chips so that the oil is not overheated. When the oil is overheated, glycerol is dehydrated to acrolein, which is a volatile substance and is highly irritating to mucous membranes. The acrolein present in the smoke is given off at the smoking temperatures. The smoke point of fat is the temperature at which smoke comes continuously from the surface of fat.

Rancidity caused by oxidation of unsaturated oils to hydroperoxides is the most common type of deterioration in snack foods during storage. Difficulty for free flowing and caking are the major problems in storage of food powders. Moisture exchange between a food product and its surrounding atmosphere as well as other biochemical changes can be controlled if adequate packaging is provided; since packaging provides a vital link between the processor and the consumer it should also offer protection from breaking, crushing etc.

Controlling the post harvest environmental conditions characterized by temperature, humidity and concentration of certain gases can reduce these losses. In controlled atmosphere storage, the atmosphere components are precisely adjusted to specific concentrations: However in modified atmosphere storage, no effort is made for controlling the atmosphere component at specific concentrations once a package has been hermetically sealed. For most of the fresh commodities, low temperature, high relative humidity, low oxygen concentration and high carbon dioxide need to be maintained in order to minimize the metabolic activities of the stored commodities.

Due to high cost of vacuum packaging and gas flushing machine, which is used for modified atmosphere storage, small-scale industries cannot afford to utilize it. Hence there is a need for low-cost packaging system.

Keeping in view the above perspectives, the present investigations on storage studies on preservation of banana and its products was undertaken with following objectives:

1. To identify and prepare products from banana like chips, banana powder and jaggery coated banana chips.
2. To standardize the thermal and physical processing conditions for the above products.
3. To conduct shelf life studies like vacuum packaging and modified atmosphere storage on bananas and its products and to suggest optimum storage conditions.

REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

Significant quantity of harvested banana is spoiled due to improper post harvest handling and storage facilities. Controlling the post harvest environmental conditions could reduce this spoilage and conversion of produce into value added products. This chapter briefly describes the review of related research and development activities done in the past few years under the following heads.

a) Storage studies on fruits and vegetables.

b) Storage studies on banana

c) Research findings of products and biproducts.

d) Development of constant temperature frying pan.

e) Storage of products.

f) Development of modified atmosphere packaging system.

g) Physio-chemical changes during storage.

2.1 Storage studies on fruits and vegetables

Fruits and vegetables are important components of our daily diet but being highly perishable as it is difficult to store these for more than 3-5 days.

Raghavan *et al.* (1984) conducted a commercial scale experiment to compare the storability of winter green cabbages in an Atmolysair System Controlled Atmosphere (ASCA) with those stored in conventional cold room. In ASCA room, the cabbages were stored for 32 weeks at a temperature of 1-3 °C and in an atmosphere consisting of 5-6 % CO_2, 2-3 % O_2 and 92 % N_2 and traces of other gases where as in control regular atmosphere room, the period of storage was the same but the temperature was 0.8 °C.

Venketesha and Reddy (1994) conducted a study on use of polyethylene bags to extend the shelf life of guava fruits. Results revealed that packaging of fruits in polyethylene bags had remarkable effect on reducing physiological loss in weight (PLW) and retention of firmness, greenness, acidity and organoleptic qualities compared to control fruits. Fruits held in 300 gauge polyethylene bag having no ventilation recorded least weight loss, retained more firmness as well as greenness and extended the other treatments developed a red over ripened spot on its surface which made the fruits unacceptable.

Meir *et al.* (1995) studied the effects of controlled atmosphere of six different compositions on the keeping quality of stored 'Hass' avocado fruits. Atmospheres containing 1, 3 and 8 % carbon dioxide in combination with 21 % oxygen and atmosphere containing 0.5, 3 and 80 % carbon dioxide in combination with 3 % oxygen were tested. Storage temperature was 5 °C and 20 °C for all treatments. Results showed that elevated carbon dioxide and reduced oxygen concentration in the atmosphere retarded ripening and reduced chilling injury during storage at 5 °C. The 8 % carbon dioxide concentration was more effective than 3 % in combination with either of the oxygen concentration. An atmosphere containing 3 % oxygen and 8 % carbon dioxide was the best with respect to the parameters mentioned above and made 9 weeks of avocado storage possible.

Izumi *et al.* (1996) stored 'Marathon' broccoli florets in air, low O_2 0.25 %. 0.5 % and 1 %) or high CO_2 (3 %, 6 % and 10 %) at 0, 5 and 10 °C. Oxygen consumption and CO_2 production were reduced under low O_2 and high CO_2 atmosphere; the reduction being greater at lower O_2 and higher CO_2 levels.

2.2 Storage studies on banana

Banana can be stored for days or weeks together by adopting proper post harvest handling operations. Depending on the distance to destination markets, banana harvested at maturity are stored in different ways such as (i) ordinary atmosphere storage at room temperature and humidity for local markets (ii) storage at a temperature slightly above 13 °C and a relative humidity of 85 to 90 % and (iii) modified atmosphere or controlled atmosphere storage at 13 °C for distant markets (Shanmugavelu *et al.*, 1985). The storage life of banana depends upon the factors like the stage of maturity at harvest, temperature, relative humidity and gas composition of storage unit.

Liu (1976) observed that dwarf cavendish banana pretreated with C_2H_4 and stored for 28 days in 1 percent O_2 or in 1/10 atmosphere pressure at 14 °C remained green and firm until the end of storage, but it started to ripen almost immediately after being placed at 21 °C without additional C_2H_4 treatment.

Apelbaum *et al.* (1977) conducted experiments with banana and concluded that the banana stored in 760 mm of Hg ripened after 30 days, while at 150 or 80 mm of Hg, it remained unripe for 120 days. The ripe fruit had every good texture, aroma and taste. A combination of 150 mm of Hg and one air exchange at every 2 h was found to create beneficial conditions for high quality banana fruit storage up to 120 days.

Amor (1989) stored Golden banana in evacuated plastic bag so that the CO_2 injury when stored in unevacuated plastic bag wherein the enzymes caused the cells of the fruit to collapse. He reported that by vacuum packing, the storage life of golden banana would be extended up to 6 weeks under refrigerated conditions (17 °C) and up to 3 weeks at room temperature.

Prabawati *et al.* (1991) conducted experiments by packing banana (Var. Rajable). Four treatment combinations of banana were packed in polyethylene (PE) bags (thickness 0.04 mm) with and without the application of low pressure (200 to 300 mm of Hg), packed in PE bags (thickness 0.08 mm) with low pressure (200 to 300 mm Hg) and as control. All the treatments were kept in corrugated carton box and stored at 15 °C. The best result was obtained by applying low pressure in PE bag (thickness 0.04 mm) for 21 days resulting in green nature fruits. After taken out from the bag, the fruits ripened normally after 9 days.

Nair and Tung (1992) studied the effect of low O_2 in Mas banana. Banana was placed in PE bags and hermetically sealed under vacuum and stored at 17 °C. The O_2 and CO_2 levels quickly equilibrated to 5 and 10 percent respectively after 7 h and remained these levels for six weeks. After storage, fruits were taken out from the bags and allowed to ripen in air at 25 °C. Under these conditions the fruits lost little weight, produced negligible C_2H_4 ripened normally when removed from storage.

Huang and Chen (1993) conducted a study on banana storage. Fruits of banana cv. Taijiao were harvested when they had 70-80 % maturity. They were first sprayed with Jiaoxuan 1 or Jiaxuan 2 (both preservative agents) or with MBC (carbendazim); after they had dried, they were wrapped in PVC film (0.015 –0.03 mm in thickness) and stored at 11-25 °C and 64-94 % RH. Results showed that fruits treated with Jiaxuan 2 could be stored satisfactorily for around 90 days.

Mohammed and Campbell (1993) studied quality changes in 'Lacatan' and 'Gros Michel' bananas stored in sealed polyethylene bags with an ethylene absorbent. Mature green fruits were packed in polyethylene (LDPE, 0.025 mm thick) bags with and without ethylene absorbents and stored at 20 °C in LDPE bags with $KMnO_4$ scored the highest overall quality.

Sarananada *et al.* (1994) conducted a study on controlled atmosphere storage of 'Embul' bananas. The effect of low O2 levels (1, 3, 5 or 7 % compared with control atmospheric level of 21 %) on the quality of 12-week-old banana cv. Embul fruits stored at 13.5 °C for 20 or 30 days were investigated. After 20 and 30 days, weight loss was lower following storage in 1, 3 and 5 % compared with control and 7 % O_2 treatments. Storage life and external appearance and eating quality of fruits were similar for 1, 3 and 5 % O_2 treatments. O_2 at 7 % did not extend storage life.

Pandyarajan *et al.* (1995) studied effect of vacuum packing on the storage life of banana. Green Rasthali bunches of three different maturities (70 %, 80 % and 100 %) were packed in polyethylene bags with air and vacuum. The average storage life fruits stored in polyethylene bags increased 4-5 times (over control) and 5-6 times when packed in vacuumed polyethylene bags. The weight loss varied from 3.8 to 10.1 % depending upon the maturity and mode of packing. The firmness of the vacuum packed fruits was found to be higher as compared to air packed samples with respect to storage days. Vacuum packed fruits took 4-5 days more to become edible to ripe as compared to those packed in air. Total sugars remained more or less same in all the test samples.

Rahman *et al.* (1995) studied the effects of temperature and modified atmosphere on the ripening of banana. Results indicated that the yellowness of the fruits was not affected by temperature over the range 14-25 °C, but fruits ripened at 14-18 °C retained more peel green color when fully ripe than those at the higher temperatures. Fruits ripened at lower temperature were firm texture, and 20 °C was found to be ideal ripening temperature with regard to flavour. Storage life could be considerably extended by sealing Apple bananas in 100 gauge polyethylene film at 13-14 °C provided the film was sufficiently permeable to prevent carbon dioxide levels from becoming toxic to the fruits. Results show that Apple bananas have similar characteristics to Cavendish bananas including respiration. Apple bananas had a high level of soluble solids at harvest which only reached a peak when the fruits were well past the fully yellow stage of ripeness. It is concluded that the percentage of marketable fruits after 12 days were 71, 38 and 22 for LDPE + $KMnO_4$, LDPE and control treatments respectively. Chilling injury symptoms developed as early as 3 days in to storage in controls at 10 °C. LDPE bags (especially containing $KMnO_4$) delayed the appearance of symptoms and severity. The presence of $KMnO_4$ reduced the ethylene concentration in LDPE bags after 12 days.

Lebibet *et al.* (1995) studied effect of storage temperature on the ripening response of banana fruit grown in the mild winter climates of Crete. Green banana fruits harvested from plants grown in green house were placed in glass jars (3-fruits/ 5-litre jar) connected to an air flow-through system with a ventilation rate of 1 litre. The jars were held at 12, 20 and 30 °C. Alternatively, fruits were placed in plastic containers (modified atmosphere storage) at 30 °C or were treated with 5 ppm. Ethylene for 24 h at 30 ^{0}C then transferred to 20 °C to ripen. Fruits stored at 30 °C in normal chlorophyll breakdown and developed heat injury after transfer to ambient temperatures. Fruits held at 13 or 20 °C developed full peel color that the ripening process was delayed. Storage at 13 °C considerably suppressed respiration rate, ethylene production and ripening. Sugars were accumulated in higher quantities in fruits stored at high temperature and modified atmosphere. Sucrose accumulation occurred earlier than that of fructose and glucose that with appropriate packing and storage conditions it is theoretically possible to store the fruits for long enough to enable transportation by sea-freight.

Elzayat (1996) reported the effects of pretreatment (dipping in thiabendazole at 400 ppm or 5 % quinolate), storage temperature (13 or 15 °C) and packaging (wrapping in polyethylene before packing in cartons) on the storage quality of banana cv. Magrabai, were investigated. Fruits were stored for one month. All packaged fruits were in good condition after storage, and had a shelf life of 5-7 days in ambient conditions. These fruits ripened normally following storage fruits turned yellow and had acceptable quality parameters as determined by TSS, moisture content, acidity, reducing sugars and total sugars decayed after storage. Control fruits were distorted in shape and decayed after storage. Carbon dioxide accumulated inside packaging during storage and reached 7.6 % (approximately) in all treatments by the third week of storage.

2.3 Research findings of products and biproducts

Prema and Chellammal (1986) conducted a survey in Trivandrum district to find out how the banana fruit was being utilized by the farm families. The survey revealed that 26 % of the families use Nendran fruits and 32 % use other varieties of banana 3 days in a week. Out of 200 families, 78 % of the families use Nendran and 98 % use other varieties of as a raw fruit. Regarding the method of storage, most of the families used ventilated rooms in which bunches were hung. After harvesting or purchasing most of the families use fruits for a week. As far as the processing is concerned around 75 % of families process banana as 'jam'. Drying banana fruits, particularly Nendran is another method of processing adopted.

A study conducted to find out the variety most suited preparing banana flour by Anonymous (1987). Banana flour prepared from six common varieties in Kerala viz. Monthan, Kunnan, Padathi, Palalyankodan, Nendran and Poovan were analyzed for chemical composition and organoleptic qualities. Chemical analysis revealed that all these varieties are rich in carbohydrates with a starch content ranging from 60 to 70 %. It also contains fair amount of minerals and fat (0.3 to 3 %). Sensory evaluation of banana flour using score card method was used to find out the most acceptable variety. Porridge prepared with banana flour, sugar and milk revealed that Nendran is better than all other varieties for quality factors such as appearance and texture.

Prasad (1988) conducted a study to develop a weaning food based on banana flour which was nutritious, low cost and acceptable. The banana flour was supplemented with horse gram, sesamum and skim milk powder to improve the nutritive value. Six combinations of the weaning formulae were developed. Protein equality of the weaning formulae were assessed through animal experiments revealed that the weaning food which contained banana flour, horse gram, sesamum and skim milk powder in the ratio 3:2:3:2 gave significantly better values of all the criteria. The acceptability of the weaning formulae was assessed by the panel of members, mothers and children. The results of the study indicated that the blend porridge was deficient in calories, vitamin A and iron. Other food ingredients were added to make up these deficiencies and two recipes were standardized. The recipes were also found to be acceptable for the panel members and children.

Singh (1993) conducted dehydration, packing and storage studies in banana fruit. Mechanical drying was found to be more satisfactory than sun drying. The packing materials influenced keeping quality. The fruit materials packed in craft paper bags, butter paper hags, polyethylene bags and polypropylene bags and open storage conditions were found to be quite unsatisfactory, as there was serious quality deterioration due to fermentation which started 50 days after storage. Storage inside a steel trunk proved effective.

2.4 Development of constant temperature frying pan

Lokra, S.S. (1993) developed fuel efficient large wood stoves applying the principles of combustion and heat transfer for a variety of operations. Thermal efficiency ranging from 35-50 % is obtained for large stoves for cooking, bath water heating, silk cocoon cooking, midday meals, Ayurvedic medicine manufacture and other cottage scale industries. Field testing of these stoves has shown their acceptability and saving of 40 to 70 % firewood over the conventional stoves.

Kneeshaw and Cragg (1997) developed a 1,000 t floor store drier equipped with fan, grain stirring equipment and gas burner was operated using a constant drying air temperature control regime of 25 °C. Drying down to 14-15 % moisture content was successfully achieved on 2 batches of grain of weight 170 and 575 t. Drying time on batch 1 (170 t) was 100.2 h with 3.1 % moisture removal, and total energy consumption for fan and heater was 29.8 kWh/t per % m.c. reduction. The second batch produced figures of 187 h, 3.04 % moisture removal and 18.44 kWh/t per % m.c. It is concluded that this technique has several advantages over conventional bulk drying systems including reduced running costs, simplified management and predictable drying times irrespective of the weather.

2.5 Storage of products

Balasubrahmanyam and Anandaswamy (1979) conducted a study on packaging requirements of fried potato chips. Packaging and storage studies of fried potato chips showed a shelf life of about 15 days in 50 g unit pouches of 100 gauge high density polyethylene, 200 gauge low density polyethylene, cello poly laminate and 300 MXX T cellophane.

Kotwaliwale *et al.* (1993) analyzed storage stability of two commercially available weaning foods. The equilibrium moisture content and water activity data obtained at 20 °C, 30 °C , 40 °C and 50 °C were used for the analysis. The analysis revealed that a range of water activity exists at all temperatures at which major moisture related changes took place in these foods. The storage stability of these foods was maximum at water activity of 0.275-0.315 and 0.285-0.350 corresponding to EMC of 0.026-0.028 g water / g dry solid and 0.047-0.055 g water /g dry solid. With increase in moisture content, the moisture binding energy decreases and moisture becomes more free.

Bache *et al.* (1997) studied the effect of packaging materials and storage temperatures on shelf life and qualities of paneer. The shelf life of paneer samples stored in different types of packages at their different temperatures revealed that the type of package and storage temperature had significant effect on it on the basis of organoleptic score. The highest shelf life of 21 days was recorded in samples packed in parchment paper and stored at 4 °C.

Sagar and Maini (1997) reported that dehydrated onion slices was stable at low temperature as compared to high temperature in respect of colour, flavour and texture. Retention of pungency as pyruvic acid was more in the samples packed in 400 gauge low density polyethylene pouches followed by 200 gauge HDPE and 150 gauge polypropylene pouches, stored at low temperate. The dehydrated onion packed in 400 gauge LPED and 200 gauge HDPE pouches exhibited less browning. The product could be stored up to 6 months in 400 gauge LDPE bags at 7 °C with 16 better pungency.

Sagar and Roy (1997) studied effect of packaging and storage of potato powder. One year storage studies revealed that the powder packed in 400 gauge polyethylene bags was more satisfactory in quality as compared to natural packed in 200 gauge polyethylene bags. The powder stored at low temperature was found better in colour and flavour. At a moisture level of 4.18 %, the optimum equilibrium relative humidity was found to be 60 %, danger point 8.04 % and critical point 10.08 % of moisture level.

Sagar *et al.* (1998) investigated influence of storage on the quality of dehydrated ripe mango slices. Dehydrated ripe mango slices could be stored at low temperature (7 °C) up to 6 months and for 4 months at room temperature (33-38.5 °C) without losing their colour flavour and texture. Low temperature helped in retaining higher levels of ascorbic acid and total carotenoids in the slices. Storage temperature, period as well as their interaction affected the quality of the product significantly.

Kumar and Sreenarayanan (2000) conducted storage studies for Pusa white onion flakes dehydrated at 60 °C with 0.3 % Potassium metabisulphite level. Shelf life studies were conducted by keeping them in 300 gauge polyethylene bags filled with Nitrogen. Results of chemical and organoleptic analysis showed reduction in ascorbic acid, higher sugar content, higher non-enzymatic browning (NEB) in control. Change in NEB was significantly lower in vacuum storage method.

2.6 Development of modified atmosphere packaging system

Celis and stenning (1995) developed a small container for controlled atmosphere storage. The system was developed from 100x75x60 cm PVC container. The main objective was to establish a dynamic equilibrium between the rate of respiration of the produce and the rate of diffusion of gases in and out of the system, thus permitting the control of these gases throughout the storage period. Cos lettuse was used for testing the CA container under a pre-established atmosphere of 3.5 % O_2 and 0.5 % CO_2. Results showed that the container could be used to provide controlled atmospheres low-cost conditions for perishable products.

2.7 Physio-chemical changes during storage

Various investigators analyzed the physio-chemical changes during storage life of fruits and its products.

2.7.1 Fruits

Post harvest deterioration of fresh produce could be caused by many factors in addition to high respiration rate, including biochemical changes associated with compositional changes, physical injuries, water loss and physiological disorders.

Studies conducted on variation in physio-chemical properties of banana and its products are reviewed under the following heads:

2.7.1.1 Firmness

Force per unit area of deformation was considered as quality index for firmness of hardness.

Desai and Deshpande (1978) reported that firmness of banana fruits decreased progressively from 3.95 to 0.36 kg/cm^2 during ripening at 20 °C and this decrease was attributed to the concomitant decrease in their starch content, cellulose and hemicellulose and increase in soluble pectin.

Delwiche and Sarig (1991) developed a probe sensor for measuring impact characteristics of various fruits and predicting firmness. Results for peaches and pears were slightly better than the system of a fruit striking a flat rigid surface. Local variations in firmness around apple surface increased the variability in sensor response.

Gupta *et al.* (1992) observed that during storage, firmness of pears decreased at all CO_2 levels probably due to softening of the outer skin of the fruit due to respiration. The loss in firmness was faster in case of ambient storage of pea.

Venketaesha and Reddy (1994) determined firmness of guava fruits by 5 kg and 13 kg capacity pressure tester for ripe and unripe fruits stored in polyethylene bags and they found that bagged ones retained more firmness as well as greenness.

Pandyarajan *et al.* (1995) observed that firmness of vacuum-packed fruits was found to be higher as compared to air packed samples with respect to storage days.

Delwiche *et al.* (1996) developed a single lane firmness sorting system, which conveyed fruit horizontally at a constant speed and caused them to impact on a rigid surface. Impact force characteristics were used to sort fruit into hard, firm and soft categories. Correlation coefficients between firmness and elasticity; were 0.84 and 0.90 for fresh market peaches and 0.78 and 0.81 for processing pears.

2.7.1.2 Physiological loss in weight

Physiological loss in weight is due to water loss through cuticle. Evaporation of water from outer surface causes decaying of epidermal cells by loss of water through the liquid -water phase of cuticular membrane to the air water interface at surface.

Persons *et al.* (1970) found that mature green tomatoes stored for 6 weeks at 12.8 °C lost an average of 1.8 percent of its original weight when stored in air as well as in various controlled atmospheres.

Scott *et al.* (1971) reported that bananas packed in sealed polyethylene bags remained in hard green condition for a period of 8-18 days where as the control fruits had ripened. Also the weight loss and mechanical injury were reduced by the use of polyethylene bags.

Dhillon *et al.* (1985) reported that the lower rate of physiological loss in weight in modified atmosphere stored fruits was clearly due to the high humidity micro atmosphere provided in the packages by the respiring fruits and to the low rate of water vapor transmission of the packaging material.

Caravalho *et al.* (1988) reported that polyethylene film wrapping delayed ripening by 4-6 days in ambient conditions and by 8 days at high RH. Loss in fruit weight and pulp peel ratio were less at the high RH.

Koca *et al.* (1993) determined the mass loss rate and overall transpiration coefficient for fresh 'Anjou' pears stored in bulk in a CA environment. Mass loss rates of 2.09 and 1.84 mg kg^{-1} h^{-1} and transpiration coefficients of 0.36 and 0.34 g kg^{-1} h^{-1} k pa were observed.

Nagaraju and Reddy (1995) found that cool chamber storage significantly slowed down the rate of increase in physiological weight loss. Also then physiological changes were slow in under nature fruits compared with those of mature fruits.

Pandyarajan *et al.* (1995) reported that the weight loss varied from 10.1 to 3.8 % from control to vacuum packed green Rasthali bunches depending upon maturity and mode of packing.

2.7.1.3 Total soluble solids

Total soluble solids (TSS) is the solid like fructose and soluble proteins present in fruit juice.

Aravindakshan (1981) showed that packaging banana in LDPE bags considerably reduced the TSS as compared to control.

Dhillon *et al.* (1985) estimated total soluble solids of sunred nectarine fruits by the hand refractometer. The results revealed that there was an increase in total soluble solids but was high both in polyethylene and paddy straw wrapping.

Singh *et al.* (1985) determined the TSS of fruits in CA storage by refractometer. It was observed that TSS decreased with increase in CO_2 concentration but increased with increase in storage period.

Firmin (1991) reported that during ripening of plantains the total sugar level significantly increased from 1.38 % to 75.5 %.

Gupta *et al.* (1992) observed that the TSS of pears stored in CA storage increased with increase in CO_2 concentration level for storage periods up to 5 to 7 days.

Naik *et al.* (1993) observed that there was an increase in TSS up to 14 days of storage when tomato fruits were stored in PE bags and thereafter decreased gradually. However, the control showed very rapid decrease in TSS.

Pandyarajan *et al.* (1995) reported that total sugar remained same in all the list samples stored at different environmental conditions.

2.7.1.4 Total carbohydrate

Carbohydrates are the important components of storage and structural materials in fruits. They exist as sugars and polysaccharides.

Fidler and North (1967) found that in the presence of 5 % CO_2, the carbohydrate loss in Cox's orange pippin apples reduced with the decrease in O_2 concentration. Since hydrolysis of starch often leads to an increase in sugar control, they conjuncted that the rate of increase in sugar content would be lower under MA than in air.

2.7.1.5 Total soluble sugar

Sugars are water soluble carbohydrate with sweet taste. There are two types of sugars present in fruits. If the sugar contains a potentially free aldehyde or ketone group they belong to reducing sugars. The other sugar component is called non reducing sugars.

The most striking chemical changes which occure during post harvest ripening banana are the hydrolysis of starch and accumulation of sugars (Loesecke, 1950). Amount 20-25 % of the pulp of the fresh green fruit is starch. In a week or so from initiation to completion of ripening the starch is almost completely hydrolysed only 1-2 % remaining in the fully ripe fruit. Sugars normally 1-2 % in the pulp of green fruits increases to 15-20 % in the ripe pulp.

Salunkhe and Wu (1973) observed that changes in total soluble sugars of fruits stored in low oxygen atmosphere inhibited sugar formation. The inhibition was more distinct in the early than in later stages.

Enough and Thomas (1980) analysed the sugar contents of fruits stored in a modified atmosphere by gas chromatography. They found that during MA storage the sugars decreased.

Wright and Kader (1997) reported that controlled atmospheres of 2 % O2, air + 12 % CO2, or 2 % O2 + 12 % CO2 had no significant effect on changes in total ascorbate content of strawberries and persimmons.

2.7.1.6 Ascorbic acid

Ascorbic acid or vitamin C content increased during ripening, but decreased in the over ripe stage. Loesecke (1950) reported that during ripening at 19 °C, ascorbic acid increased slightly at the time of early development of yellow colour, then fell gradually with complete yellowing to 10 to 12 mg per 100 g of pulp.

Koksal (1989) carried out analysis to determine the changes in Vitamin C contents of pomegranate during the storage period, revealed that beginning from the first month, in all temperature degrees, there were significant losses. Vitamin C content of the fruit stored at 1 °C was better retained than the other temperature.

2.7.1.7 Titrable acidity

During ripening, titrable acidity of pulp increases to a peak in the case of some varieties and then declines. This follows the same trend as starch hydrolysis i.e. when hydrolysis is proceeding most rapidly; the acidity is increasing most markedly and as the rate of hydrolysis is reduced, acidity becomes progressively less (Loesecke, 1950).

Fidler and North (1967) inferred that the acid content in Cox's orange pippin apples decreased logarithmically with storage period. The rate of acid loss decreased with the reduction in temperature, O_2 concentration and with increase in CO_2 concentration as long as the fruit remained free from unaerobiosis, low temperature break down and CO_2 injury.

2.7.1.8 Microbial spoilage of fruits

Area affected by fungal pathogens on the surface of fruits was taken as percentage decay.

Singh (1985) conducted studies on storage of tomatoes in enriched CO_2 atmosphere and assessed the decay percentage as the percentage of fruits in which rotting had just started. It was observed that there was no decay at all CO_2 levels for a storage period of 8 days and subsequently the decay percentage increased with increase in storage days.

Gupta *et al.* (1992) carried out studies on storage of pears in controlled environment containing different concentrations of CO_2 at 5±2 °C. Decay percentage was estimated by manual sorting and it was found that the decay, percentage decreased at 4 % CO_2 level.

Ocknokwo *et al.* (1990) identified that the fungal pathogens which showed cellulolytic activities were *Boteyodiplodia theobromae*, *Aspergillus niger* and *Rhizopus* sp. These organisms caused rot at room temperature, but were unable to cause rot at low temperature.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the experimental techniques employed for measurement and analysis of various objective functions. Details of the techniques employed for measurement, test procedures and materials used have been given under following heads.

a. Storage studies of banana fruits.
b. Identification and preparation of banana products.
c. Design and development of constant temperature frying pan.
d. Storage of products.
e. Setting up of a low cost modified atmosphere storage system.
f. Physio-chemical changes during storage.

3.1 Storage studies of banana fruits.

Storage studies on fresh banana fruits were conducted at Banana Research Station, Kannara, Trichur, which is one of the leading research centers in Kerala where research exclusively on banana are being carried out under Kerala Agricultural University.

Fresh banana (four different varieties namely Nendran, Robusta, Palayankodan and Poovan) bunches of commercial maturity were harvested from the farm. The bunches were carefully dehanded and split into lots containing 3-5 fruits. The fruits were washed in tap water to remove latex, soil particles and floral remnants and allowed to dry overnight in shade to remove moisture present on the surface. Physical observations like length, girth, diameter and weight were noted. The length and girth were measured by using a scale and cotton thread. The diameter was measured using vernier caliper and the fruits were weighed using electronic balance. The preliminary observations are tabulated in Table 1.

Table 1. Preliminary observations of banana fruits.

Name of variety	Average surface area (cm^2)	Average length (cm)	Average girth(cm)	Average Weight (g)	Average Width (cm)
Nendran	130.00	20.05	13.50	172.00	4.28
Robusta	98.00	18.75	9.80	70.00	2.96
Poovan	75.00	13.46	10.10	57.50	3.02
Palayankodan	60.00	11.54	9.30	43.60	2.48

The samples were then exposed to following environmental conditions up to 20 days for the storage studies.

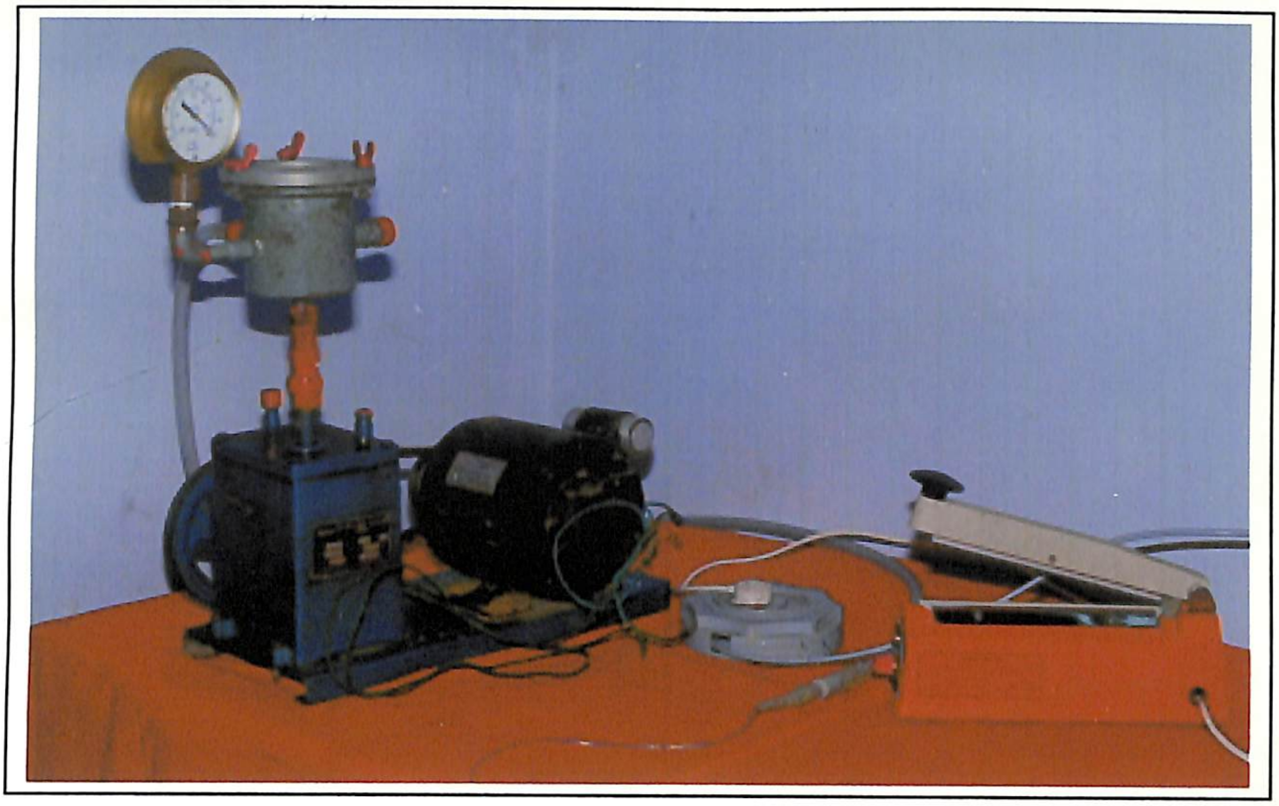
1. Control (fruits stored in open atmosphere)
2. Stored in refrigerator at 15 °C.
3. Sealed in evacuated polyethylene bags and stored in open atmosphere.
4. Sealed in evacuated polyethylene bags and stored in refrigerator at 15 °C.

3.1.1 Vacuum Packaging of banana fruits.

The experimental set up for vacuum packing consists mainly of a vacuum pump and a hand sealing machine (Plate 1).

The banana fruits were kept in polyethylene bags of thickness 350 gauge and the bags were sealed using a hand sealing machine leaving a small opening just sufficient to insert a 3 mm plastic pipe into the polyethylene bag. One end of 3 mm plastic pipe was connected at the inlet of vacuum pump and its other end was inserted into the bag through the opening already provided. The tube was held properly using the forefinger and thumb so as to remove the air from the bag smoothly. The air inside the bag containing banana was removed with the help of vacuum pump. As soon as the entire air was removed from the packet, the opening was sealed using the hand sealing machine. The samples were then stored under control, refrigerated, vacuumed polyethylene bags and refrigerated cum vacuumed polyethylene bags.

Plate 1. Set up for vacuum packaging of banana



3.1.2 Experimental Design

Details of the treatments are given here under:

a. Control (stored in open atmosphere)

b. Stored in refrigerator at 15 °C.

c. Sealed in evacuated polyethylene bags and stored in open atmosphere.

d. Sealed in evacuated polyethylene bags and stored in refrigerator at 15 °C.

The following symbols were used to represent different treatments for different varieties.

Nendran

Control	: GNC
Refrigerated storage	: GNR
Vacuum packed	: GNV
Refrigerated cum vacuum packed	: GNRV

Palayankodan

Control	: GPC
Refrigerated storage	: GPR
Vacuum packed	: GPV
Refrigerated cum vacuum packed	: GPRV

Robusta

Control	: GRC
Refrigerated	: GRR
Vacuum packed	: GRV
Refrigerated cum vacuum packed	: GRRV

Poovan

Control	: GPoC
Refrigerated	: GPoR
Vacuum packed	: GPoV
Refrigerated cum vacuum packed	: GPoRV

3.1.2.1 Independent factors

The following independent parameters were used in the experiments

i. Storage period
ii. Package environment

3.1.2.2 Dependent factors

The following physio-chemical and micro-biological characteristics were taken as dependent factors of this study.

i. Firmness
ii. Total soluble solids
iii. Physiological loss in weight
iv. Total soluble sugar
v. Total carbohydrates
vi. Ascorbic acid
Vii. Titrable acidity
Viii. Fungal spoilage of fruits

3.1.3 Quality changes during storage of banana fruits

The changes occurring in the fruits and its products during storage are important phenomenon for assessing the quality and shelf life. The physio-chemical characteristics were determined as described below.

3.1.3.1 Physical changes

The physical changes observed during storage were explained here under the following titles:

3.1.3.1.1 Firmness

Firmness is an important attribute in fruits in connection with crop harvest, quality evaluation during storage for fresh market as prior to processing. The penetrometer (Plate 2) was used to measure the firmness of fruits. It consisted of two platforms, the upper one for keeping weight and the lower one for keeping fruit. The lower platform was adjustable, in order to bring the fruit in contact with the plunger rod before measuring firmness.

A plunger, of 6mm dia. was fixed to the upper platform through a spring for automatic release and was calibrated with a dial gauge for measuring firmness of depth of penetration in mm. The fruits were kept on lower platform and which was adjusted to make the fruit touch with the plunger rod. A 5000 gm was kept in the upper platform; and depth of penetration was noted from the dial gauge in mm.

3.1.3.1.2 Total soluble solids

Three or four fruits were selected at random and was made in to pulp using a mixer grinder. Small sample of the fruit pulp was filtered through muslin cloth and a drop of filtrate was taken to determine total soluble solids using hand refractometer (Make: Erma). TSS was expressed in °Brix as suggested by Ranganna in 1995.

3.1.3.1.3 Physiological loss in weight

Fruits were weighed during storage at four days interval with help of an electronic balance. The fruits free from surface moisture were weighed. The initial and final weight of the fruit were recorded. Percentage physiological loss in fruit weight was calculated by the formula given below:

$$\text{Physiological loss in weight (Percentage)} = \frac{\text{Initial weight} - \text{Weight after storing} \times 100}{\text{Initial weight}}$$

3.1.3.2 Chemical changes

Procedures for the determination of chemical changes are briefly explained here.

Plate 2. Penetrometer

3.1.3.2.1 Total carbohydrates

Carbohydrates are the important components of storage and structural materials in the plants. They exist as free sugars and polysaccharides. The basic units of carbohydrates are monosaccharides that can not be split by hydrolysis in to more simple sugars. The carbohydrate content can be measured by hydrolyzing the polysaccharides into simple sugars by acid hydrolysis and estimating the resultant monosaccharides. The total carbohydrates in banana samples was estimated by Anthrone method (Sadasivan and Manikom, 1992).

Exactly 100 mg of fruit was ground with 5ml of 2.5 N HCl and transferred into a boiling tube. It was kept in a boiling water bath for 13 h and cooled to room temperature and hydrolysis was done. Then it was neutralized with solid sodium carbonate until the effervescence ceased. The volume was then made up to 100 ml and centrifuged. The supernatant was collected and 0.2 ml aliquot was taken for analysis. The standards were prepared by taking 0.0, 0.2, 0.4, 0.6, 0.8 and 1.0 ml of the working standard glucose solution (100 mg 100^{-1} ml) into six test tubes. Then the volume was made up to 1.0 ml in all the test tubes including the sample tubes by adding distilled water. The contents of all the tubes were cooled on ice. Then 4.0 ml of anthrone reagent (200 mg of anthrone dissolved in 100ml of ice cold 95 percent H_2SO_4) was added to all test tubes and heated for eight minutes in the boiling water bath. After cooling, the absorbance was read at 630 nm.

A standard graph was prepared connecting the concentration in x-axis and optical density in Y-axis. The carbohydrates present in 100 mg of fruit was calculated from the carbohydrates present in 0.2 ml solution. The standard graph is shown in Appendix I.

3.1.3.2.2 Total soluble sugar

Exactly 100 mg of fruit was taken and ground nicely with 10 ml of 80 % ethanol and transferred to a test tube. From this 0.5 ml of the solution was pipetted out into a boiling tube and kept on the water bath until it dried completely. For the determination of the total soluble sugars, the same procedure adopted for the determination of total carbohydrates was followed.

3.1.3.2.3 Ascorbic acid

Ascorbic acid otherwise known as vitamin C was measured by dye method (Sadasivan and Manikom, 1992)

Exactly 100 gm of ascorbic acid was taken and dissolved in 100 ml of 4 % oxalic acid to get the standard solution. Then 10 ml of the standard solution was pipetted out and diluted to 100 ml with same oxalic acid and titrated against the dye (52 mg dye and 42 mg sodium bicarbonate in 200 ml distilled water). End point was the appearance of pink color that persisted for few minutes. The titration was repeated for concordant values. The amount of dye consumed (V_1) was equivalent to the ascorbic acid present.

The fruit pulp was prepared from 5 g of fruit and the pulp was made up to 100 ml with 4 % oxalic acid. About 5 ml of this made up to solution was pipetted out into a conical flask containing 10 ml of 4 % oxalic acid and titration was done with the dye as above. The titration was repeated for concordant values (V_2).

Amount of ascorbic acid present in 100 g of fruit was calculated as follows:

$$\text{Ascorbic acid content per 100 mg of fruit sample} = \frac{0.5\text{mg} \times V_2\text{ml} \times 100\text{ml} \times 100}{V_1\text{ml} \times 5\text{ml} \times \text{weight of sample}}$$

3.1.3.2.4 Titrable acidity

The sample was macerated in a glass mortar. The pulp material was weighed, boiled in water for 1 h cooled and then filtered into a volumetric flask. Then 5 ml of filtrate was taken and diluted with distilled water and titrated with 0.1 N NaOH using few drops of 1 % phenolphthalein as indicator. The filter value was recorded. The results were expressed as % unhydrous citric acid (Ranganna, 1995).

$$\text{Percent unhydrous citric acid} = \frac{\text{Titre value} \times \text{Normality of NaOH} \times \text{Volume made up} \times \text{Equivalent weight of acid} \times 100}{\text{Volume of sample taken} \times 1000}$$

3.1.3.3 Microbial Spoilage of fruits

The percentage of fruits spoilage due to fungal pathogens in different treatments during storage was calculated using the formulae.

$$\text{Microbial spoilage (Percentage)} = \frac{\text{Area effected by fungal pathogens}}{\text{Total surface area}} \times 100$$

3.2 Preparation of products and technology development.

Three products identified for standardizing the processing conditions and for storage studies were a) banana chips; b) jaggery coated chips and c) banana powder. A detailed description of the recipes adopted for preparation of the products are also given here.

Banana chips, one of the major bakery product which is commonly consumed by Keralites requires optimization of frying temperature and duration. As such an extensive study was conducted to standardize the above conditions. Banana powder is consumed as natural weaning food for babies from six months onwards. The preparation and storage study of banana powder will help to extend the shelf life. During Onam and other festivals, jaggery coated banana chips are an attractive menu in the traditional feast. A study on the storability of jaggery coated banana chips was also carried out.

3.2.1 Chips

Materials and recipes used for making chips are explained here.

Materials

Banana slices - 300 g

Oil - 900 ml

Salt solution - 15 ml of 10% solution.

Fresh banana (Nendran variety) of commercial maturity was used for making chips. The bunches were carefully dehanded, split into lots containing not lower than three numbers. Each lot was weighed using a weighing balance. Fruits were peeled using a stainless steel knife, the weight of peeled and unpeeled banana were recorded. The fruits were sliced into 1.5 mm thick small pieces as by usual practice. The primary observations of preparation of banana chips are shown in Table.2.

Table.2. Primary observations relating to preparation of banana chips (Nendran Variety)

Number of hand from peduncle	Average No. of fruits per hand	Weight of banana hand (kg)	Length of fruit(cm)	Weight of peeled banana (g)	Length of peeled banana (cm)	No. of slices from one fruit
1	10	1.985	18.72	251.85	16.00	84
2	11	1.950	21.77	214.45	16.12	88
3	10	1.800	20.85	211.25	14.98	83
4	10	1.540	20.16	153.35	14.38	78
5	9	1.140	21.50	151.25	14.13	76

The oil in the frying pan was heated to about 95-125 °C and samples of banana slices, uniformly weighing 300 g, were put into the oil. Salt solution was added two minutes before frying was completed. After frying, the oil is drained off and cooled to room temperature. Then it was stored in polyethylene bags.

3.2.1.1 Development of constant temperature frying pan

The constant temperature frying pan mainly consisted of

a. Frying pan
b. Heating chamber with coil
c. Digital indicating type Automatic controller.

3.2.1.1.1 Frying pan

The frying pan was made up of mild steel plate of thickness 3 mm. A round mild steel plate was made into a vessel of hemispherical shape of 450 mm diameter and 150 mm depth at center. Two handles were provided at diametrically opposite sides on the edge of the vessel. An arrangement for measuring temperature through a thermocouple was also provided. A separate thermocouple of range 32- 400 °C was inserted into the frying pan during the time of operation. (See Plate 3). Sectional view of constant temperature is also shown in Fig. 1.

3.2.1.1.2 Heating chamber with coil.

The unit mainly consisted of double walled cylindrical chamber with refractory slats and heating elements. The design drawing of the unit is shown in Fig. 2, Plate 4.

The cylindrical chamber mainly was consisted of double walled mild steel construction of following size

Outside diameter	- 385 mm
Inside diameter	- 335 mm
Height	- 205 mm

The space between the two walls at the bottom and sides was filled with best quality glass wool so as to reduce the heat loss. Inside the chamber, on both bottom and sidewall 6-mm thick asbestos millboard lining was provided to safeguard the operator.

Eleven number of 'T" shaped refractory slats of size 10.5 x 3 x 0.5 cm were mounted radially at the bottom of the cylinder. Two heating coils (Power rating 4.5 kw) made from best quality Nickel chrome resistance wires of 1.5 mm dia. helically wound spring (10 mm dia. and 5 mm pitch) with lengths 384 mm and 250 mm were used to develop the required temperature.

One end of the coil L_1 (length 384 mm) was fixed at the bottom-center of the chamber through an asbestos block of size 50 x 35 x 3 mm. The coil was made in the shape of spiral with uniform radial spacing. Four such windings were made over the eleven refractory slats. Eleven numbers refractory slats of size 10.5 x 3 x 0.5 cm were kept above previously mounted refractory slats keeping the heating coil in position. The other end of the heating coil was connected to the supply mains through an asbestos block of size 110 x 35 x 3 mm.

The second coil of length L_2 (250 mm) was wound inside the chamber in a spiral arrangement with uniform vertical spacing of 20 mm.

The ends of the coils were fixed to an asbestos piece of size 50 x 35 x 3 mm bolted on the inside wall of the heating chamber. A thermocouple to measure up to 600 °C is also placed inside the heating chamber through the asbestos piece at a distance 5 cm from the horizontal surface of the heating chamber.

A side box of size 18 x 5 x 4 cm was provided to enclose the connections to heating elements. The box extends horizontally up to center of the heating chamber.

3.2.1.1.3 Digital indicating type Automatic Temperature controller

A separate wall mounted temperature control unit, consisting of the following, was provided for temperature control.

- Digital indicating type temperature controller.
- Air break magnetic contactor
- Thermocouple with lead wires.
- On/Off switch
- Indicator lights.

Digital indicating type automatic controller of the range 32 to 600 °C with built in thermocouple, fail safe and cold junction compensating devices of suitable range is used to regulate the temperature. The electric circuit diagram of digital indicating type temperature controller is shown in Fig.3.

Air break magnetic contactor was used for switching ON and OFF under any load condition. It is provided with automatic arrangement to come to OFF position when abnormal current flows through the circuit due to over load, short circuit or earth faults.

Thermocouple of range 32 to 600 °C was used for measuring the temperature inside the heating chamber On/Off switch and indicator lights were provided along with temperature controller.

3.2.1.2 Optimization of processing conditions

Banana chips, which is one of the most popular snacks used by Keralites, require optimization of frying temperature and time for its preparation. Quality of chips also depends on quality of oil and the flame used to heat. As such an extensive study was conducted to standardize the above conditions.

It is important to control frying temperatures so that the oil is not overheated. At high temperatures smoke is produced from the surface of oil causing production of acrolein. This may irritate mucous membranes of the consumers while eating.

Plate 3. Constant temperature frying pan in operation

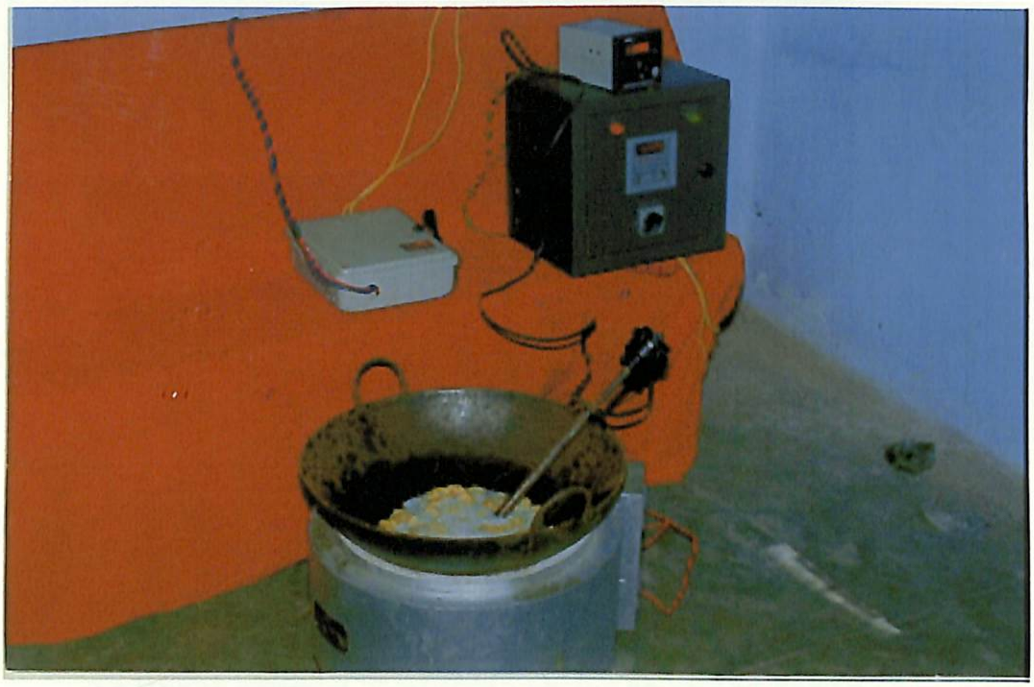
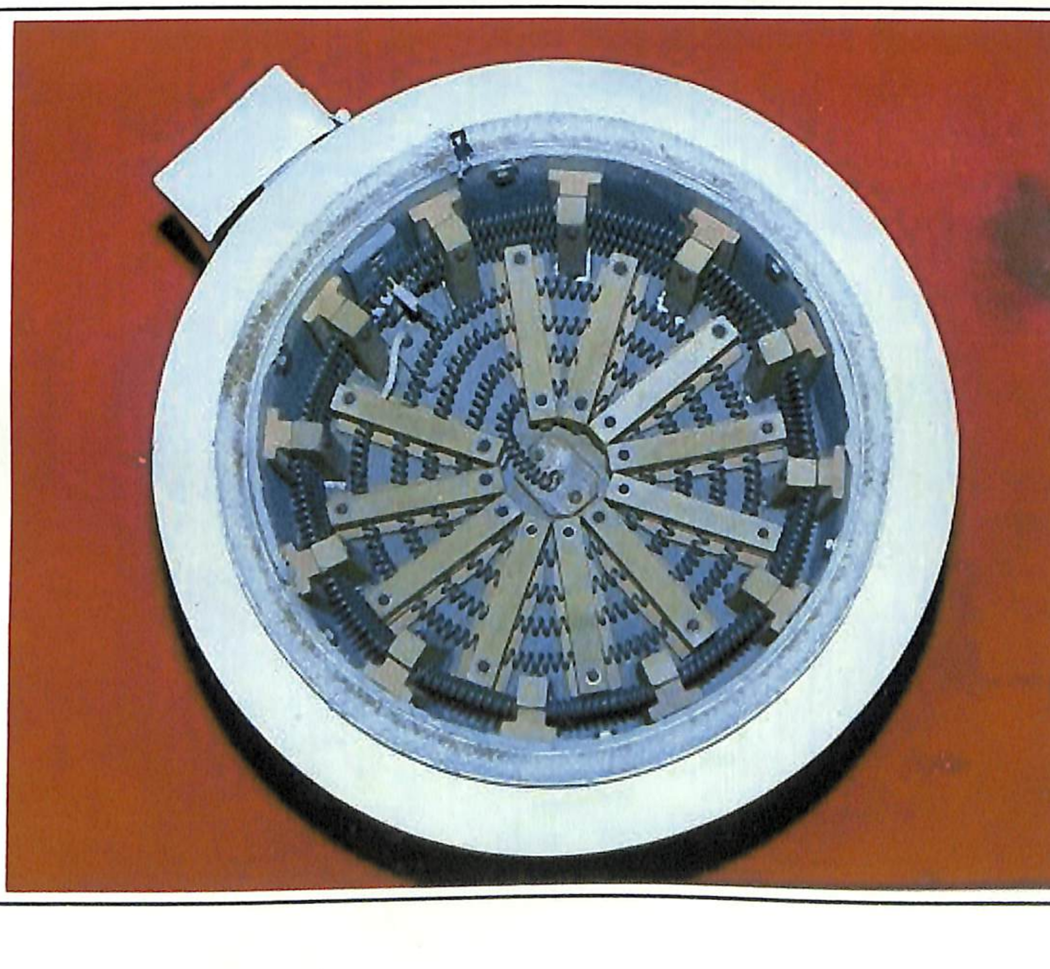
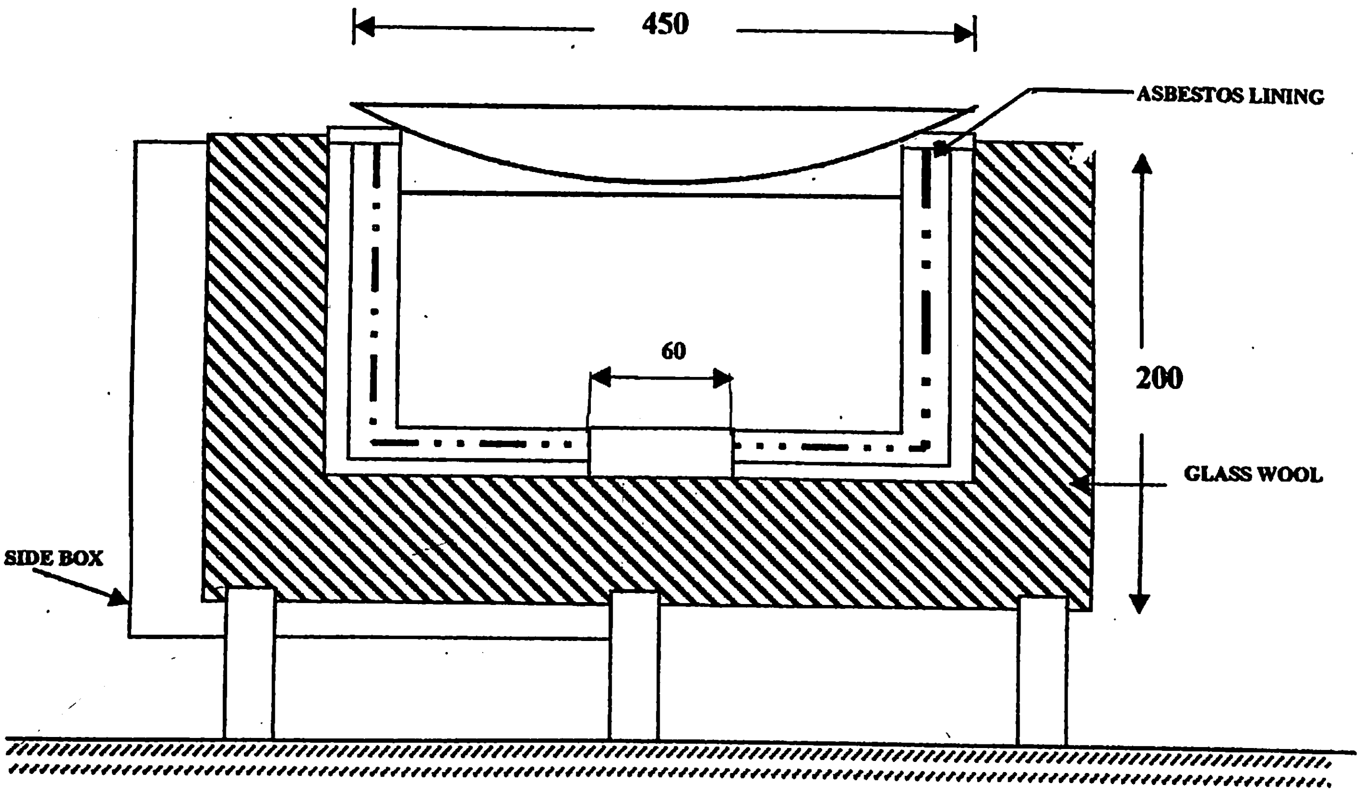


Plate 4. Heating chamber





All dimensions in mm

Fig. 1 Sectional view of constant temperature frying pan set up

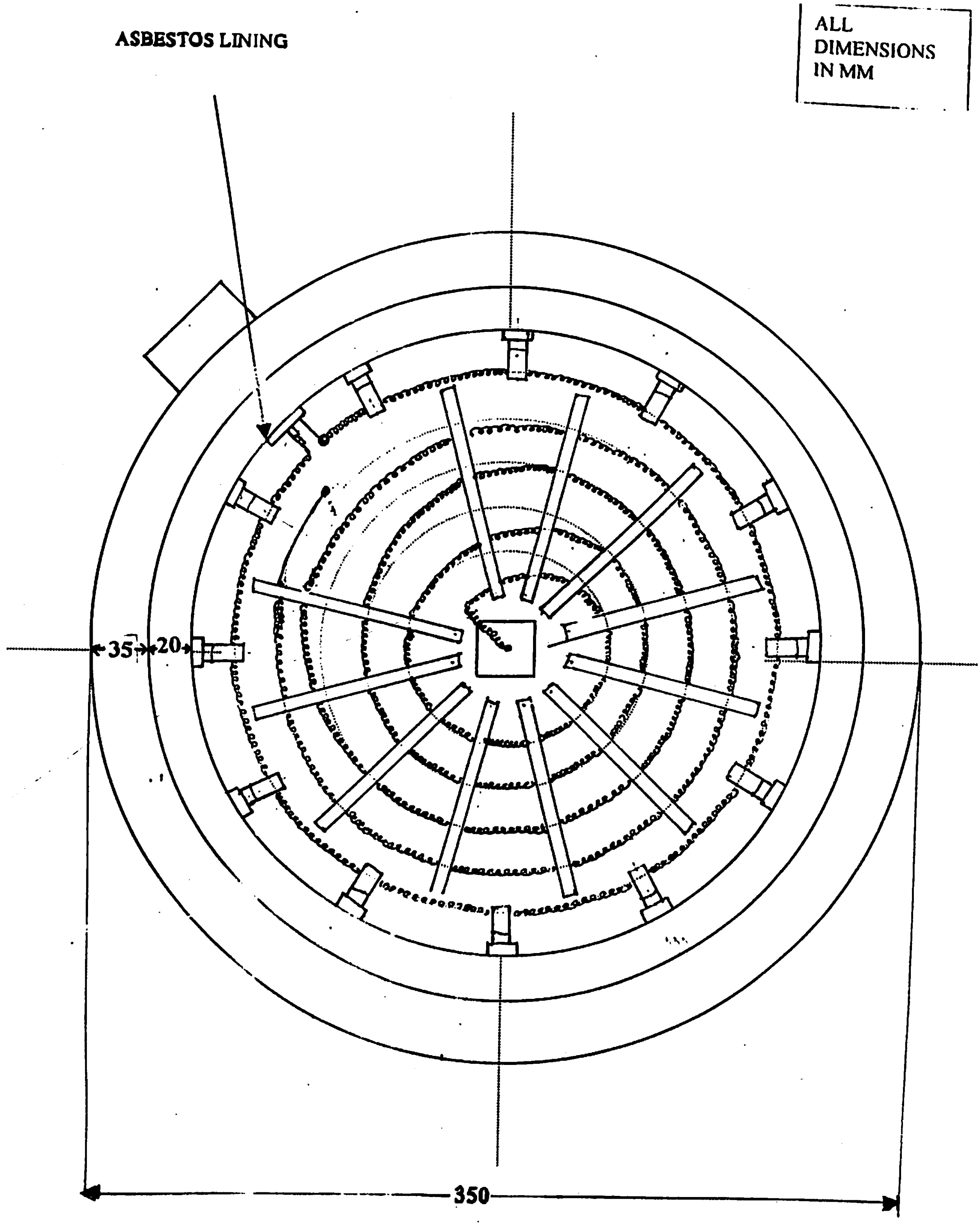


Fig. 2 Heating Chamber

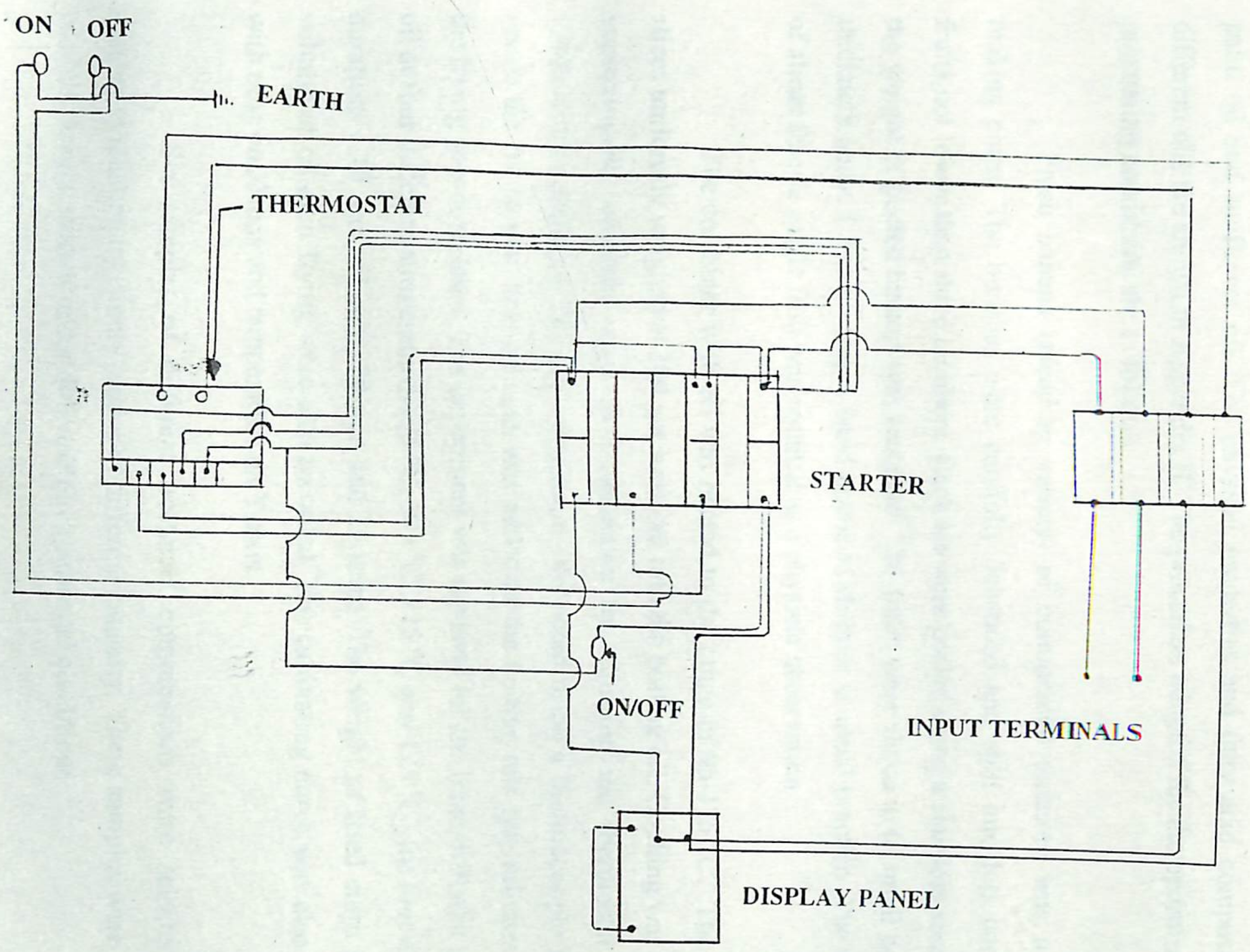


Fig. 3 Electrical circuit diagram of Digital indicating type Automatic Temperature Controller

Banana slices were fried in three different types of oil viz. coconut oil, palm oil and sunflower oil. The physical properties and fatty acid composition of different oils are shown in Appendix II. The procedure adopted for the optimization of processing conditions are as follows:

Fresh banana (Nendran variety) of commercial maturity was used for making chips. The bunches were carefully dehanded and split into lots containing fruits not lower than three numbers. Each lot were peeled using a stainless steel knife, the weight of peeled banana was recorded. The fruits were sliced in to small pieces of thickness about 1.5 mm using a hand operated chipper as usual practice. The number of slices from a single fruit was counted as a physical observation

The container with oil was heated to the range of 95-125 °C. The banana slices uniformly weighed at 300 gm were put into the boiling oil. Cooking was done at approximately constant range of temperature by adjusting the thermostat of the temperature controller. The oil temperature was noted using a thermocouple inserted inside the frying pan. Salt solution was added to the boiling oils two minutes before the frying gets completed. The experiment was repeated for the three different types of oil at four different temperatures (95 °C, 105 °C, 115 °C and 125 °C) for four different durations (10 min, 15 min, 20 min and 25 min). The weight of fried chips and the volume of oil after frying were also recorded. The calibrating curve was also plotted with time on X-axis and temperature on Y-axis.

Six samples of different treatment combinations were selected using sensory evaluation by twenty judges of different category. These samples were used to conduct storage studies under different environmental conditions.

Symbols used to denote the different treatments are shown here:

Coconut oil	O1
Palm oil	O2
Sunflower oil	O3
Temperature 95°C	T1
Temperature 105°C	T2
Temperature 115°C	T3
Temperature 125°C	T4
Duration 10 min	D1
Duration 15 min	D2
Duration 20 min	D3
Duration 25 min	D4

3.2.1.3 Development of low cost modified atmosphere storage system.

The experimental set up for modified atmosphere packaging is shown in Fig. 4 (Plate 5). The various components of the system consisted of the following:

a) Nitrogen flow line
b) Vacuum line
c) Pipe line set up

3.2.1.3.1 Nitrogen flow line

A cylinder containing Nitrogen capacity of 7 m^3 was used to supply Nitrogen gas during modified atmosphere packaging. A regulator connected to the outlet of the cylinder controlled the flow of gas. A PVC pipe of dia. 10 mm was connected to the regulator. The other end of the pipe was immersed in water in an airtight vessel so that the gas flow could be regulated easily. The outlet pipe from the vessel was connected to the valve 2 of the pipeline set up.

3.2.1.3.2 Vacuum line

A rotary vane type high vacuum pump of capacity 50 lpm driven by 0.25 hp motor was used to create vacuum inside the packets to be stored. The inlet of the vacuum pump was connected to the valve 1 of the pipe line set-up by a PVC pipe of dia 10 mm.

3.2.1.3.3 Pipe line setup

The pipeline set-up consisted of three one way valves and PVC pipe of dia 20 mm. A plastic pipe of dia. 3 mm is connected to valve 3. to the package to be stored

3.2.1.3 Modified atmosphere storage of banana chips

Popular banana products i.e., chips, powder and jaggery coated chips were used for the storage studies. The product weighing 30 gm was kept in a 250 gauge polyethylene cover of size 10 x 10 cms.

The cover was sealed using a hand sealing machine leaving a small opening just sufficient to insert a 3 mm plastic pipe in to the polyethylene cover. The 3 mm plastic pipe from the main pipeline setup was inserted into the cover through the opening already provided. The tube was held properly using forefinger and thumb so as to remove the air from the packet smoothly. The valves (1) and (3) were opened (See Fig. 4). Thus the entire air was removed. Then the nitrogen from the cylinder was permitted to enter into the packet. As soon as the cover was filled with nitrogen, the packet was sealed using a hand-sealing machine. This packet was placed inside a 500 gauge polyethylene cover of size 10 x 15 cms in order to protect the first packet from mechanical damages during handling. This cover was again filled with Nitrogen as described earlier. The permeability properties of the packaging materials are shown in Appendix III.

Plate 5. Low cost modified atmosphere packaging system

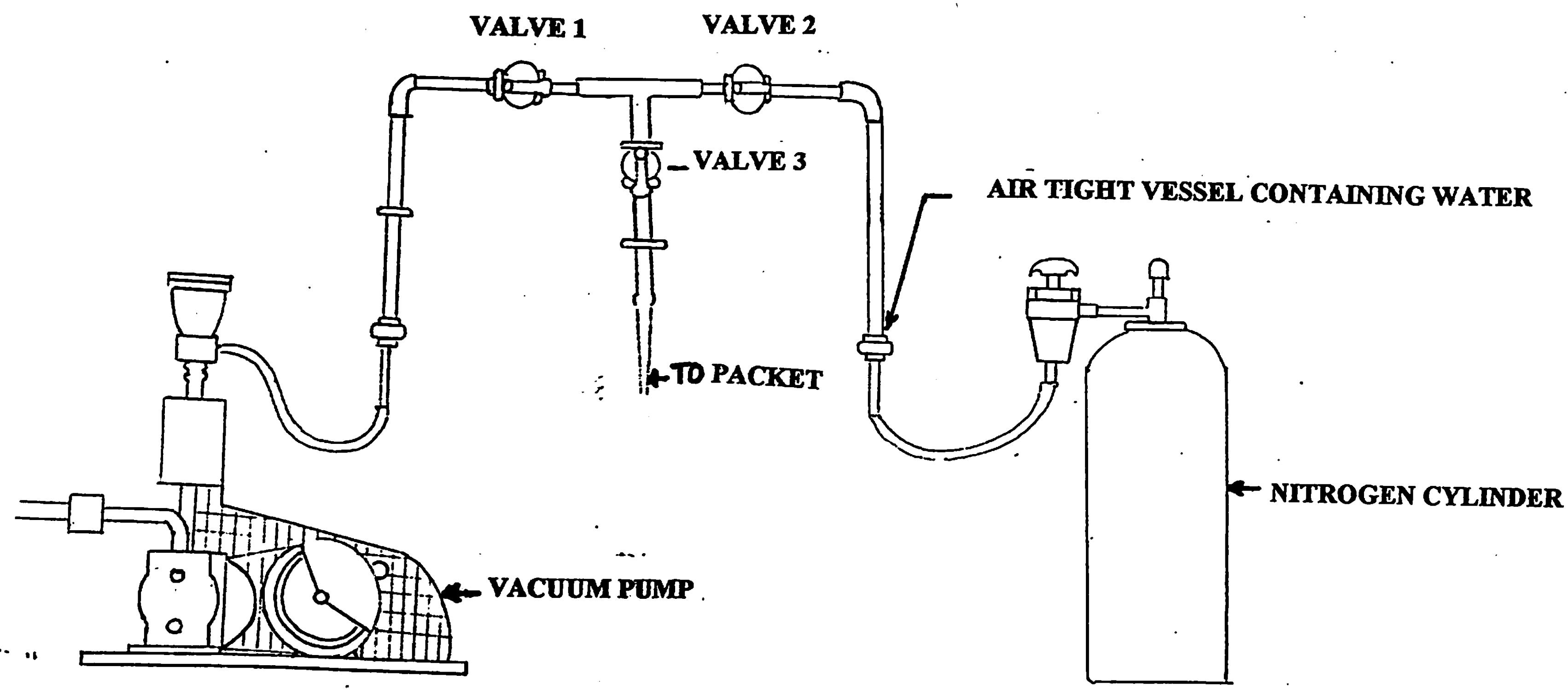


Fig. 4. Low cost modified atmosphere packaging system

3.2.1.4 Experimental Design

The details of the treatments are described here:

a) Control (stored in polypropylene cover of thickness 150 gauge and size 10 x 10 cm).

b) Air packing (stored in 500-gauge polyethylene cover of size 10 x 15 cm)

c) Vacuum packing (stored in evacuated 250gauge polyethylene cover of size 10 x 10 cm and the cover is kept in 500 gauge evacuated polyethylene cover of size 10 x 15 cm)

d) Nitrogen packing (stored in Nitrogen filled 250-gauge polyethylene cover of size 10 x 10 cm and the cover is kept in 500-gauge nitrogen filled cover of size 10 x 15 cm)

The following symbols were used to denote the different packaging treatments for different products.

C Control (Packed in Poly propylene pouches of thikness 150 gauge and size 10 x 10 cm).

A Air packing (stored in 500-gauge polyethylene cover of size 10 x 15 cm)

V Vacuum packing (stored in evacuated 250 gauge polyethylene cover of size, 10 x 10 cm and the cover is kept in 500 gauge evacuated polyethylene cover of size 10 x 15 cm)

N Nitrogen packing (stored in Nitrogen filled 250-gauge polyethylene cover of size 10 x 10 cm and the cover is kept in 500-gauge nitrogen filled cover of size 10 x 15 cm)

3.2.1.5 Quality changes during storage

Observations made during Storage are explained here under physical, chemical, microbial, equilibrium relative humidity and organoleptic changes.

3.2.1.5.1 Physical observation

Physical observation made during storage of chips was moisture content.

3.2.1.5.1.1 Moisture content

Moisture content was determined by oven drying method (Ranganna, 1995). Chips weighing 10 gm was kept in a metallic container. The metallic container was placed in an oven of temperature 70 °C for 16-18 h. After drying lid replaced, cooled and the sample was reweighed. The sample was reheated until consecutive readings did not vary much.

$$\text{Moisture content (percentage)} = \frac{\text{Initial weight-final weight x 100}}{\text{Initial weight}}$$

3.2.1.5.2 Chemical changes

Rancidity in terms of acid value was recorded as a chemical observation during storage of chips.

3.2.1.5.2.1 Rancidity

The acid value is a measure of the extent to which the glycerides in the oil have been decomposed to lipase or other action. The decomposition is accelerated by heat and light. As rancidity is usually accompanied by free fatty acid formation, its determination is often used as a general indication of edibility of oil.

Exactly 25 ml of diethyl ether was mixed with 25 ml alcohol and 1 ml of phenolphthalein (1 %) and carefully neutralized with 0.1 M sodium hydroxide. 1-10 gm of oil or melted fat is mixed with neutral solvent and titrated with aqueous 0.1 M sodium hydroxide shaking constantly until a blue color persists for 15 seconds.

$$\text{Acid value} = \frac{\text{Titration (ml) x 5.61}}{\text{Wt of sample}}$$

3.2.1.5.3 Microbial changes of chips

Many of microbial changes that occur in packed foods are related to humidity and atmosphere within the packages. The quality of food is based on kind of micro organisms present which can be assessed by serial dilution and plating method for the differential enumeration of bacteria, yeast and fungi.

Change in total count of bacteria and fungi were found out for microbial changes of chips.

3.2.1.5.3.1 Enumeration of bacteria

The growth of bacteria was very rapid and depends upon the nature of food material, moisture temperature and air. Commonly used media for the enumeration of bacteria is Nutrient Agar Media. The composition of medium for the growth of these organisms are listed in Appendix IV.

3.2.1.5.3.2 Enumeration of Fungi

The majority of the spoilage found in packed foods are due to fungi. The overall value of the commodity effected by unsightly superficial contamination, even though its palatability is not affected. Commonly used media for the enumeration of fungi is Martin's Rose Bengal Agar medium (Martin's Rose Bengal Agar Medium).

3.2.1.5.4 Equilibrium relative Humidity studies

To study the storage behavior of foods in general and dehydrated food in particular, the measurement of equilibrium relative humidity (ERH) is of considerable importance. ERH was determined by Wink's weight equilibrium method (Ranganna, 1995).

Approximately 40 ml of saturated salt solution was poured into dessicator. 5-10 g of the sample was spread uniformly on petridishes. The moisture content of sample was determined by drying in a vacuum oven at 70 °C. The dishes were exposed to different relative humidities ranging from 0 to 98 %, inside the dessicators containing saturated solutions of different salts having definite relative humidities at 25 °C and 37 °C (Appendix V). The gain or loss in weight of sample at the end of 1, 2, 3, 4, 5 and 6 h and thereafter at intervals of 24 h up to 360 h was noted with a view to determine the moisture equilibrium. During this period any changes in the product like discoloration and mould growth were noted to obtain critical point and storage characteristics of the product. The weight of the product was noted when there was no further loss or gain. The equilibrium moisture content at each relative humidity studied was calculated using the expression: X = A - B, where X is dry matter content in the sample taken for determination of ERH, A is the weight of sample taken, and B is the moisture content.

$$\text{Equilibrium moisture content (\%)} = (S-X) \times 100/S$$

where S is weight of sample after equilibrium

3.2.1.5.4 Organoleptic properties

Organoleptic tests for the various products were carried out by a panel of 40 judges and they rated the quality of the banana products by assigning ranks, adopting the rating given:

Like extremely	9
Like very much	8
Like moderately	7
Like slightly	6
Neither like not dislike	5
Dislike slightly	4
Dislike moderately	3
Dislike very much	2
Dislike extremely	1

The average score was worked out for each sample from the rating made by the panel of judges and comparisons were made. The general acceptability rating (score) was considered as the criteria of judging the quality of the product. Two-way Factorial (ANOVA) and Students Neuman Kuel's Test were used for statistical analysis. Score sheet for individual judge is shown in Appendix VI.

3.2.2 Jaggery coated banana chips

The following are the recipes and materials used for the preparation of jaggery coated chips.

Materials

Peeled banana	- 1 kg
Jaggery	- 500 g
Dried ginger	- 25 g
Cardamom	- 10 No.
Cumin	- 30 g

Matured fruits of Nendran variety were selected. The skin was removed using stainless steel knife and then the core was cut into three/four pieces longitudinally. Pieces of 7.5 mm average thickness were made from the above pieces. The pieces were fried in coconut oil on low flame. After frying, the oil was drained off.

The jaggery was allowed to melt in a container by keeping it with a little water on medium flame. The powdered spices were added to the melted jaggery. The fried pieces were added to it by continuous stirring till it reached the required consistency.

3.2.2.1 Storage studies of jaggery coated chips

Storage studies were conducted in the same way as in the case of chips.

3.2.2.2 Experimental Design

The details of the treatments are shown here:

a) Control (stored in polypropylene cover of thickness and size 10 x 10 cms).

b) Air packing (stored in 500-gauge polyethylene cover of size 10 x 15 cms)

c) Vacuum packing (stored in evacuated 250-gauge polyethylene cover of size, 10 x 10 cms and the cover is kept in 500 gauge evacuated polyethylene cover of size 10 x 15 cms)

d) Nitrogen packing (stored in Nitrogen filled 250-gauge polyethylene cover of size 10 x 10 cms and the cover is kept in 500-gauge nitrogen filled cover of size 10 x 15 cms)

3.2.2.3 Quality changes during storage

Observations made during storage are explained here with the following titles.

3.2.2.3.1 Moisture content

The method adopted for the determination of moisture content was same as that for chips explained under section 3.2.1.5.1.1.

3.2.2.3.2 Microbial changes of Jaggery coated chips

Change in total count of bacteria, yeast and fungi were recorded as microbial changes. Bacteria and fungi were recorded as the same as in the method for chips. Enumeration of yeast is explained here under

3.2.2.3.2.1 Enumeration of yeast

A variety of yeast genera can usually be found on fruits and these organisms being about the spoilage of fruit or fruit products. Many yeasts are capable of attacking the sugars found to bring about fermentation, with the production of alcohol and CO_2.

Commonly used media for the enumeration of yeast is yeast extract Malt extract Agar medium. The composition of medium is shown in Appendix IV. This medium was used for the determination of total count of yeast.

3.2.2.3.3 Equilibrium relative Humidity studies

The method described for the equilibrium relative humidity studies for chips was also used for jaggery coated banana chips explained under the section 3.2.1.5.4..

3.2.3 Banana powder

In Kerala, banana flour is prepared from fully matured banana especially Kunnnan and Nendran varieties and is used as a weaning food for babies from six month onwards. Banana powder was prepared by the method described by Aravindakshan *et al.* (1991). Fully matured and unripe bananas were selected. The peeled bananas were cut into slices and sun dried. Then it was powdered and sieved through 120-mm sieve.

3.2.3.1 Storage studies of banana powder

The details of the treatments are shown here:

a) Control (stored in polypropylene cover of thickness 150 gauge and size 10 x 10 cms).

b) Air packing (stored in 500-gauge polyethylene cover of size 10 x 15 cms)

c) Vacuum packing (packed in muslin cover of size 8 x 10 cms in order to prevent banana powder from being sucked in to the vacuum pump and stored in evacuated 250 gauge polyethylene cover of size,10×10 cm and the cover was kept in 500 gauge evacuated polyethylene cover of size 10×15 cm)

d) Nitrogen packing (stored in muslin cover of size 8X10 cms and then stored in Nitrogen filled 250-gauge polyethylene cover f size 10×10 cm and the cover is kept in 500-gauge nitrogen filled cover of size 10×15 cm)

3.2.3.2 Observations made

The observations made during the storage of powder were as follows:

3.2.3.2.1 Moisture content

The moisture content was determined by oven drying method (Ranganna, 1995) described earlier for chips under the section 3.2.1.5.1.1.

3.2.3.2.2 Chemical changes

Chemical observations made during storage of powder were total sulphur dioxide content and enzymatic browning

3.2.3.2.2.1 Total Sulphur dioxide Content

Sulphur dioxide is an oxygen acceptor and therefore it acts as an antioxidant. It reacts with aldehyde group of sugars so that they are no longer free to combine with amino acids.

Five ml of NaOH was added to two aliquots of each sample and gently stirred, being careful not to beat air in to the solution, and the samples were allowed to stand for 20 min. Seven ml of 5N HCl was added to one of the samples, with stirring to avoid local concentration. The sample was then titrated with 0.02N Iodine using starch solution as indicator. The titration measures the total iodine reducing value of the sample. Let this be (c).

The second sample was acidified with 7ml of 5N HCl. Ten ml of formaldehyde was added (about 36-40 %) to bind the sulphite, and then the sample was allowed to stand for 10min. At the end of this period, the sample was titrated with

0.02 N Iodine after the addition of starch solution till a dark blue color persists for at least 15 s. Let this be (d). Volume of iodine used by the total SO_2 present in the sample is equal to (c-d) ml.

$$SO_2 \text{ in ppm} = \frac{\text{Titre x } 0.64 \text{ x } 1000}{\text{Wt of sample}}$$

3.2.3.2.2.2 Non Enzymatic browning

Ascorbic acid as well as pentose sugar gives rise to furfural which may polymerize or combine with amino compounds to cause non-enzymatic browning.

About 4-5 gm of sample was extracted with 60 % alcohol for 12 h and filtered. The color was measured at 420 mm using aqueous alcohol as blank (Ranganna, 1995).

3.2.3.2.3 Microbial Changes

The change in microbial count was observed as it was for chips under the section 3.2.1.5.3.

3.2.3.2.4 Equilibrium Relative Humidity studies

To study the storage behavior of food powders equilibrium relative humidity (ERH) studies were conducted (Ranganna, 1995) as explained earlier for chips under the section 3.2.1.5.4.

RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

The results of the experiments are discussed in this chapter with the following titles.

4.1 Effect of packaging environments on storage period

The presence of oxygen in the atmosphere has a strong effect in determining the quality of stored food materials. The food products stored in packets are highly sensitive to the available oxygen in that environment. Here, the effect of variations in the environment inside the packets was closely observed (See plate 6&7)

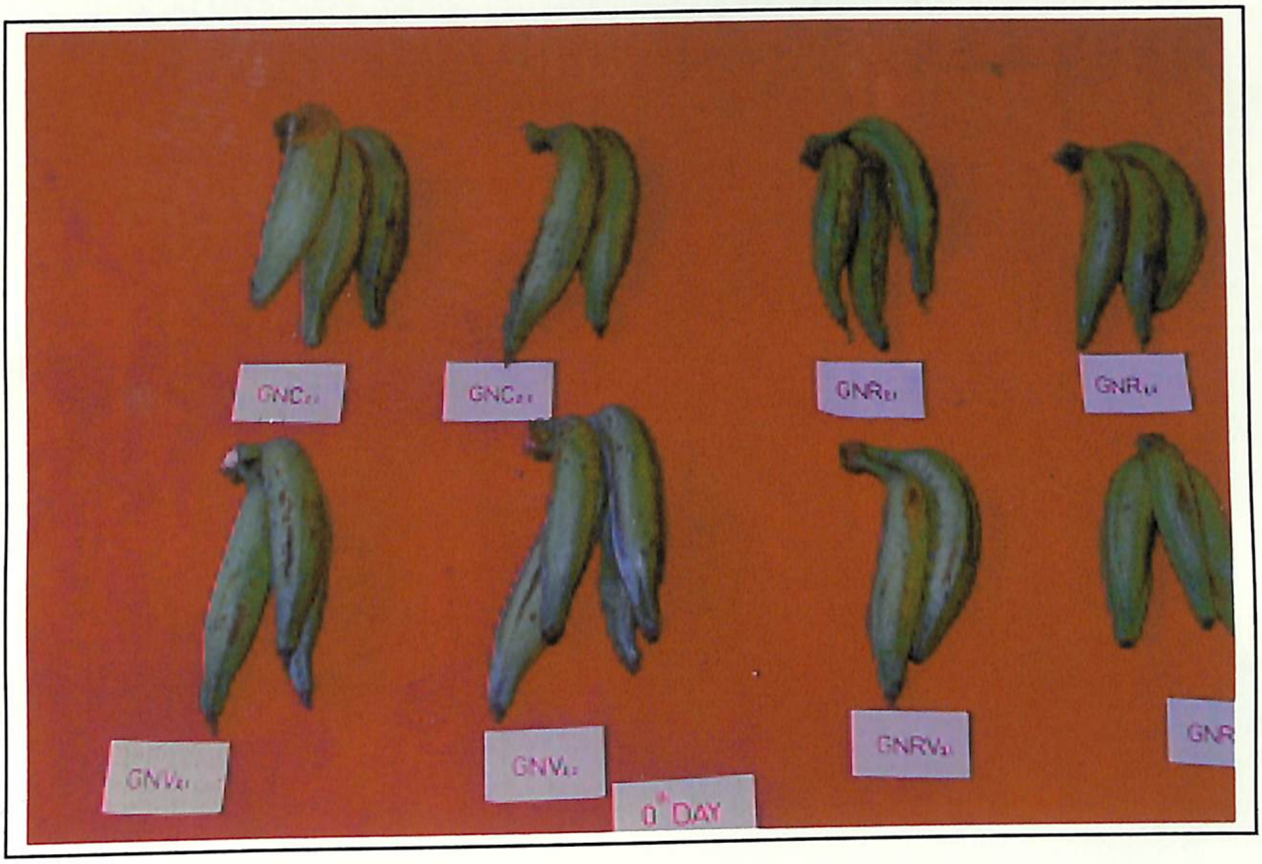
The refrigerated cum vacuum packed sample retained the original colour till the end of 20th day and it's firmness was more or less the same as in the first day. The refrigerated fruits showed black color spreading on the surface of fruits initiated from 5th day of storage. It is presumed that this may be due to chilling injury of fruits. Vacuum packed banana found appreciably the original colour even after the 14th day of storage. The fruits stored under control remained with out much change till fourth day of storage .The fruits under control were ripened on 7th day of storage and completely decayed after 12th day of storage. All the varieties of fruits under this study showed the same pattern. The changes were explained as physical changes, chemical changes and microbial changes.

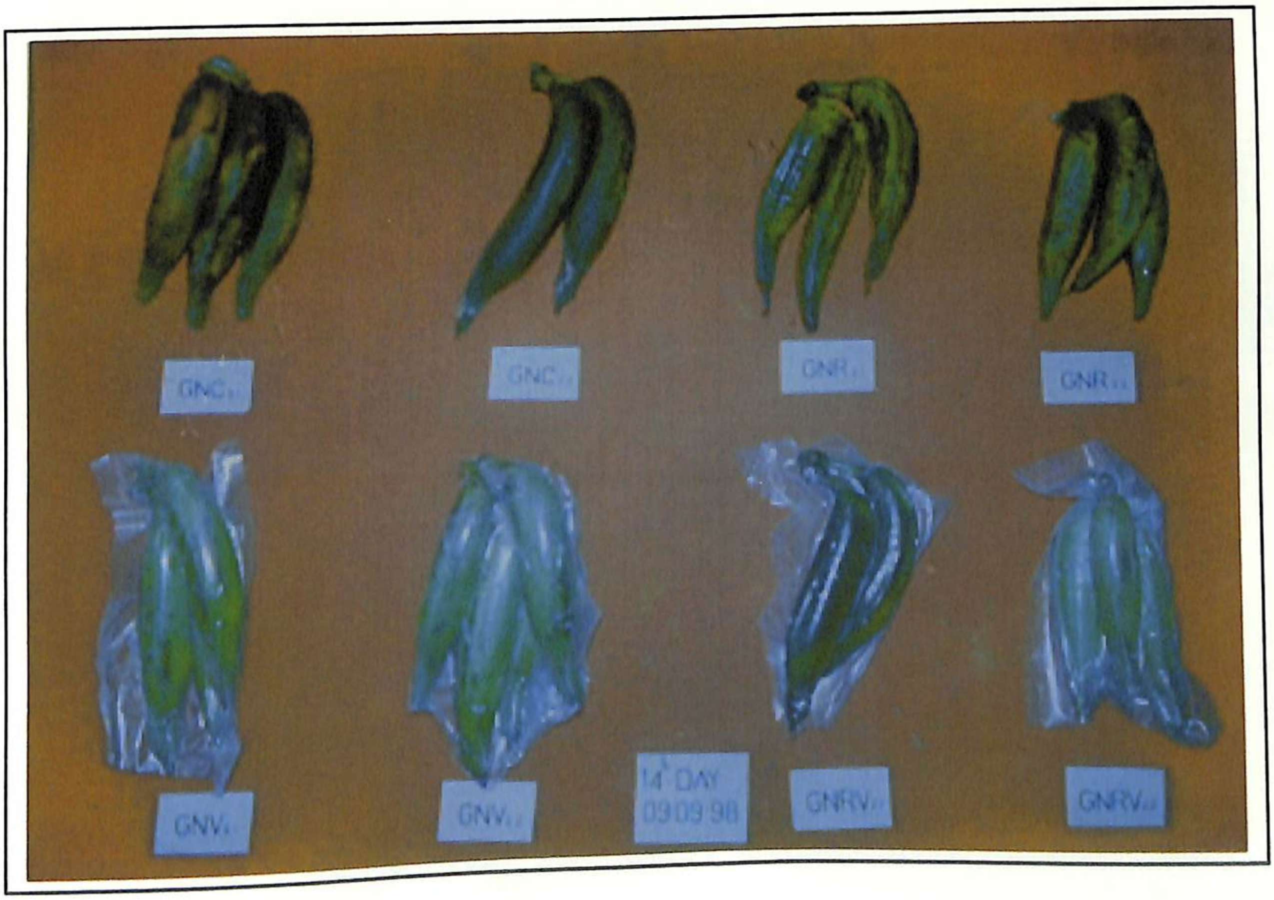
4.1.1 Firmness

Firmness of fruits was affected by the packaging environment and storage period (Fig. 5). Nendran showed minimum value of penetration in vacuum cum refrigerated fruits on the 16th day of storage and depth of penetration was maximum at control conditions (6.07 mm).

For Robusta, the maximum value of penetration was observed at 12th day of storage at control. Poovan variety showed the same trend of variation. The

Plate 6&7. Effect of packaging environments on storage of banana fruits





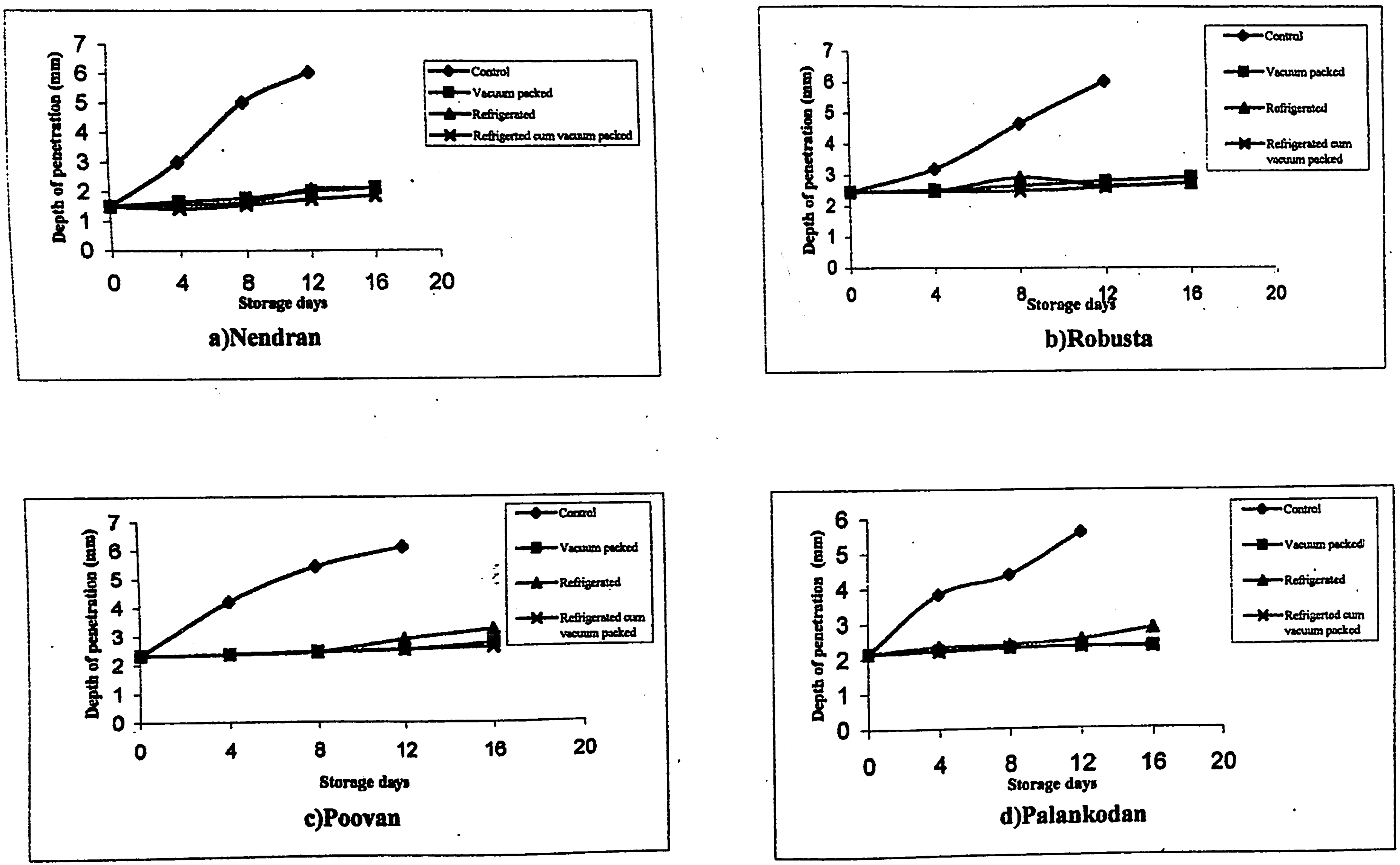


Fig.5 Variation of firmness during storage days

maximum value of penetration was 6.13 mm on the 12th day of storage at control, whereas the minimum value was observed for vacuum cum refrigerated stored (1.86 mm on 16th day)

Palayankodan fruits stored under control showed 6.45 mm penetration on 12th day of storage and it was the maximum. The minimum value recorded was 2.40 mm under vacuum cum refrigerated after 16 days of storage.

The reduction in the firmness of the fruit was due to the breakdown of starch and pectin which are mainly responsible for the firmness of the fruit. It was reported that pectin and starch content decrease continuously with storage period. Vacuum packing slowed down the metabolic activity by limiting the oxygen supply and creating an elevated level of carbon dioxide by respiration (Gorris and Peppelenbos, 1992).

Considering the interaction between package environment and storage period, the depth of penetration increased while firmness decreased from first day of storage. All the varieties of fruits under investigation showed the same trend of variation.

4.1.2 Total Soluble Solids

The variation of Total Soluble Solids (TSS) for different varities of banana are shown in Fig. 6.

Nendran showed maximum value of TSS (26.4 °Brix) at 12th day of storage under control conditions. TSS value was minimum (3.23 °Brix) for Nendran under vacuum cum refrigerated condition on the 16th day of storage. Similarly other varities showed maximum at 12th day of storage under control and minimum 16 day of storage under refrigerated vacuum.

The values for Robusta were 22.7 °Brix (maximum) and 4.17 °Brix (minimum). The maximum TSS value for Poovan was 23.45 °Brix and minimum

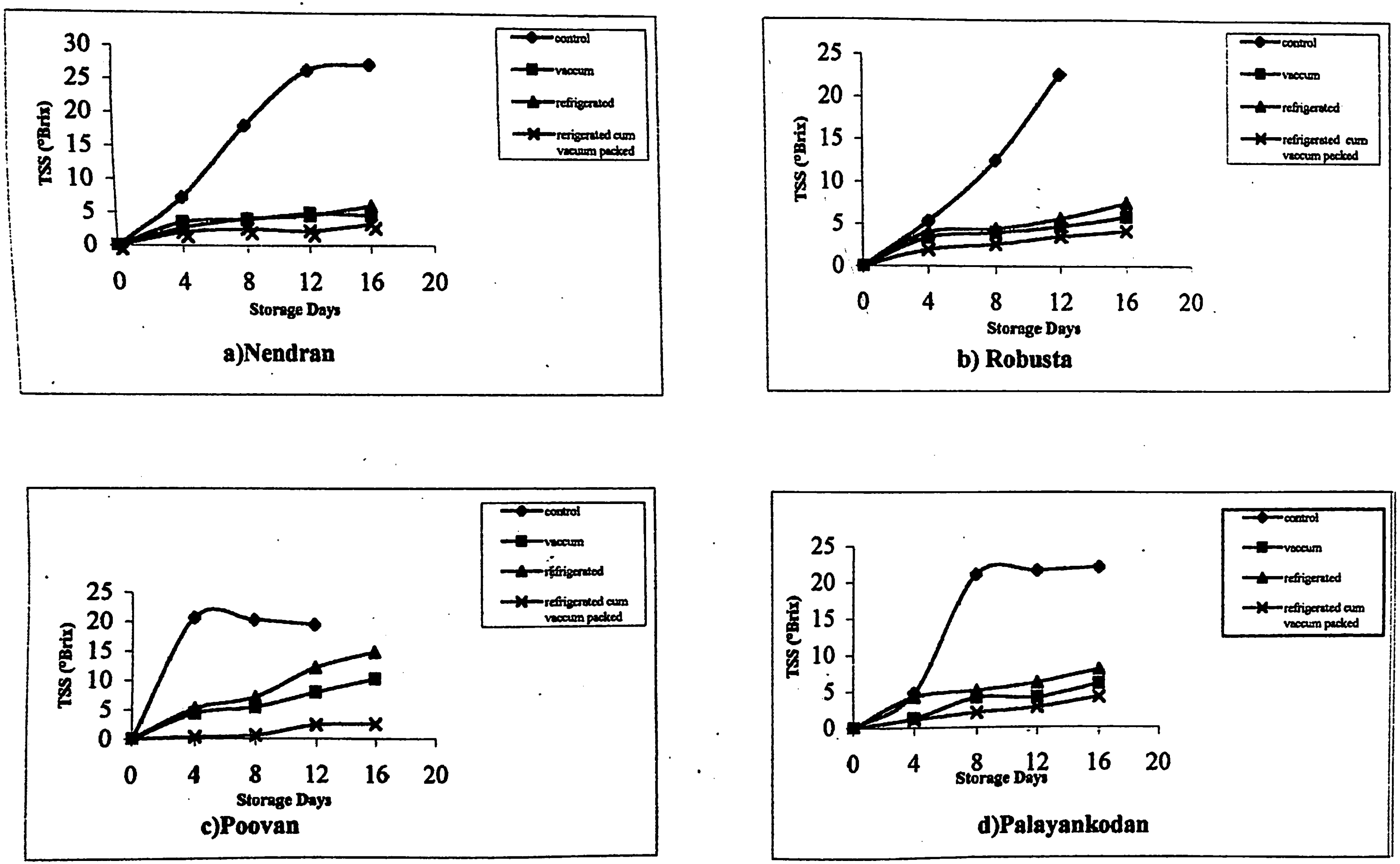


Fig.6 Variation of total soluble solids with storage period

2.5 °Brix. For Palayankodan it was 22.17 °Brix (maximum) and minimum 4.20 °Brix after the storage period.

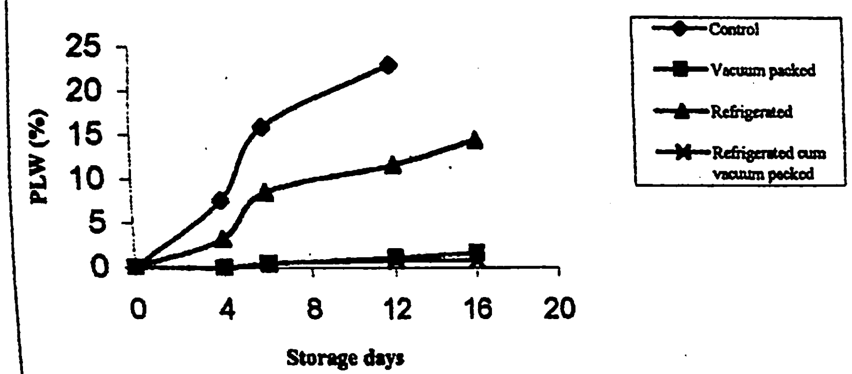
Of all the treatments banana stored under vacuum cum refrigerated condition was found to be the best. Considering the effect of storage period on package environment it was found that TSS increased gradually in all treatments. From these results it is derived that TSS was lowest in vacuum cum refrigerated condition. This may be due to belated ripening of fruits in packages. The level of TSS increased due to increase in sugar content. The increasing trend of TSS was reported by Firmin (1991) for banana.

4.1.3 Physiological loss in weight

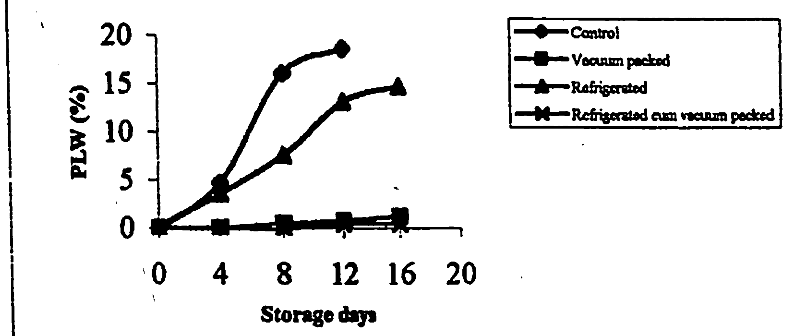
The variation of percentage physiological loss in weight obtained for the treatments during storage of different varieties of banana are shown in Fig. 7. From the figure it is clear that the weight loss was maximum for fruits stored under control. For Nendran fruits stored under control, weight loss was found to be 28.14 % after 12 days of storage and minimum weight loss was recorded for fruits stored under refrigerated vacuum. (0.86 %). Nendran fruits showed physiological weight loss of 1.69 % after 16 days of storage under vacuum at ambient conditions and the fruits stored under refrigerated storage (15 °C) showed 14.61 % weight loss.

In the case of Robusta variety of fruits, the samples kept as control showed weight loss of 18.76 % stored after 12 days. The fruits stored under vacuum cum refrigerated showed a loss of weight of 0.46 % after 16 days of storage. The fruits stored under vacuum as control showed weight loss of 1.25 % and the fruits stored under refrigerated condition showed weight loss of 14.81 %

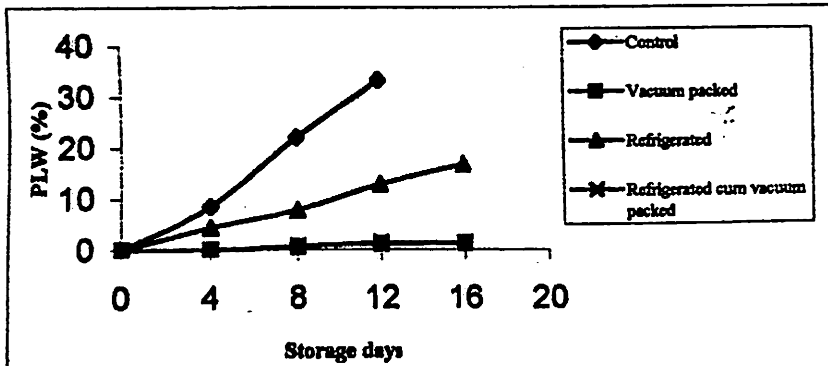
Loss in physiological weight of Poovan fruits under control was maximum ie.33.39 %. The fruits stored under vacuum cum refrigerated packed showed least value ie.1.27 %. The fruits stored under refrigerated condition showed 16.83 % physiological loss in weight.



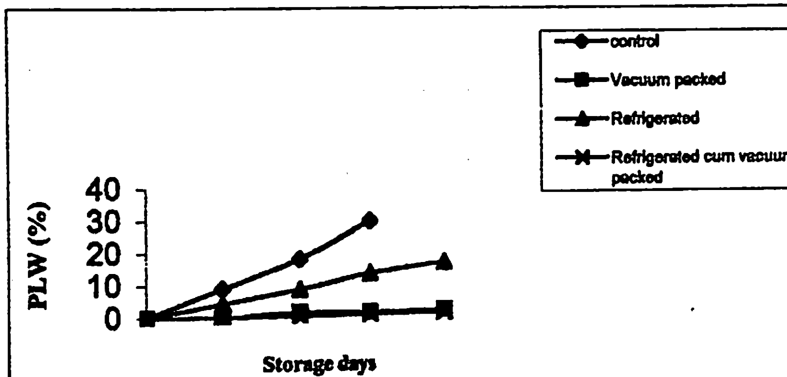
a)Nendran



b)Robusta



c)Poovan



d)Palayankodan

Fig.7 Variation of physiological loss in weight with storage period

Fruits under control exhibited the maximum weight loss of Palayankodan fruits (29.65 %) and fruits stored under refrigerated cum vacuum conditions showed 0.99 % weight loss. Fruits stored under refrigerated condition showed 16.7 % and the fruits stored under vacuum conditions showed 1.74 % weight loss.

The results observed from the Fig. 7 showed that weight loss was maximum for control and minimum for vacuum cum refrigerated condition. Of all the treatments banana packed under vacuum cum refrigerated condition was found to be the best. The retarded rate of respiration and low water vapour transmission rate may be the reason for reduction in physiological weight loss..

4.1.4 Total Carbohydrates

The change of total carbohydrate content during storage is shown in Fig. 8. For Nendran fruits exhibited an increase in total carbohydrate from 14.57 mg 100^{-1} g to 18.64 mg 100^{-1} g and then declines to 15.13 mg 100^{-1} g on 12th day of storage for fruits stored under control.

The fruits stored under vacuum cum refrigerated condition showed total carbohydrate content of 16.08 mg 100^{-1} g. The fruits stored under refrigerated condition showed total carbohydrate content of 16.76 mg 100^{-1} g and fruits stored under evacuated condition showed 16.56 mg 100^{-1} g on 16th day of storage.

Robusta and the other varieties of banana fruits showed the same trend of variation. The total carbohydrate for Robusta (control) increased from 13.51 to 19.34 mg 100^{-1} g on 8th day of storage and then declined to 17.53 mg 100^{-1} g. The total carbohydrate content of Robusta stored under vacuum cum refrigerated condition on the 16th day was 14.77 mg 100^{-1} g . Robusta stored under refrigeration and vacuum packaging showed total carbohydrate content of 16.98 mg 100^{-1} g and 15.69 mg 100^{-1} g, respectively.

Poovan kept as control showed initial carbohydrate content of 12.50 mg 100^{-1}g. It increased from 12.50 mg 100^{-1} g to 19.80 mg 100^{-1}g and then declined to

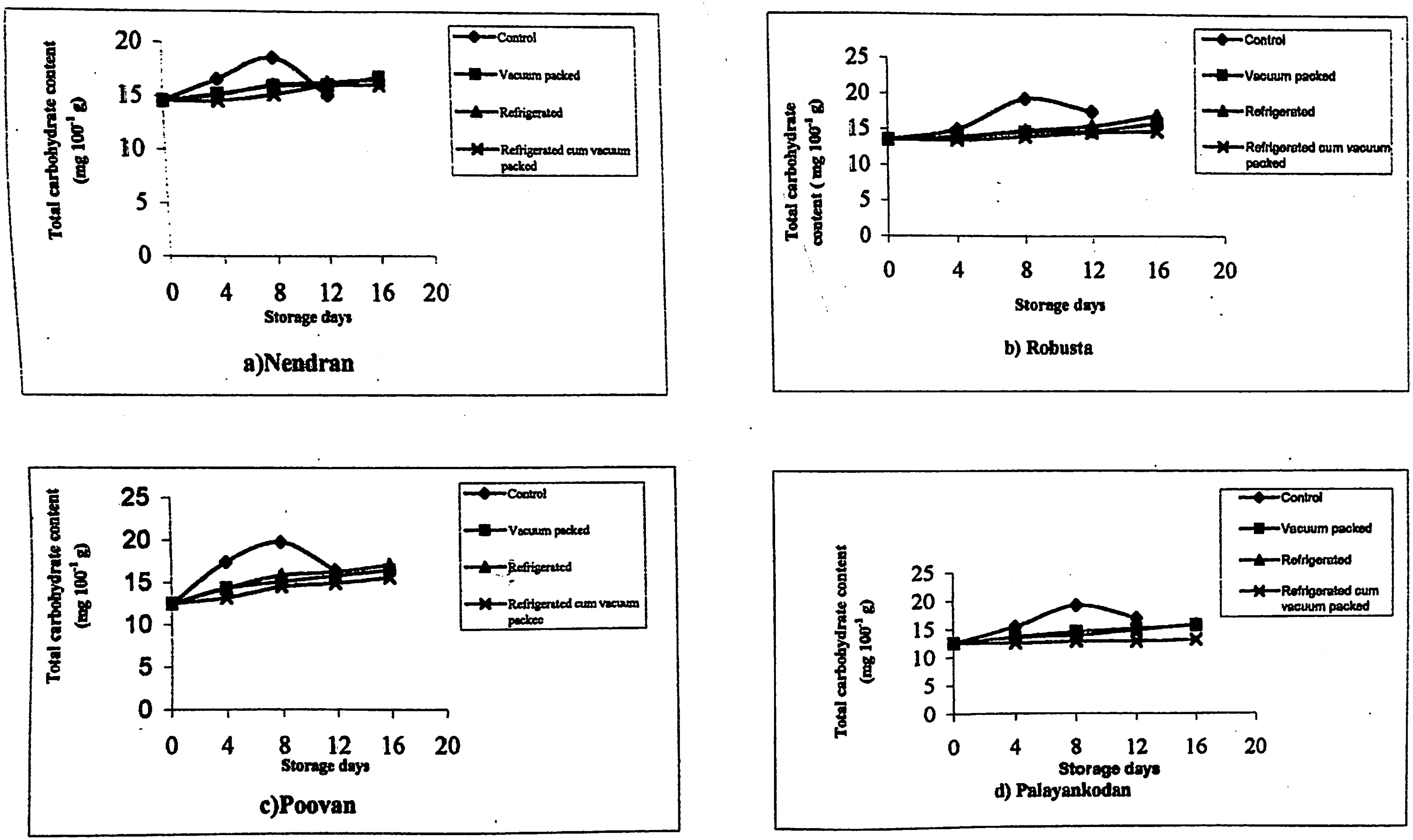


Fig.8 Variation of total carbohydrate content with storage period

16.50 mg 100^{-1} g. The fruits under vacuum cum refrigerated showed 15.62 mg 100^{-1} g at the end of 15^{th} day. The fruits stored under vacuum and refrigerated condition increased from 12.5 to16.5 mg 100^{-1} g and 17.1 mg 100^{-1} g respectively on the 16 th day

The initial carbohydrate content of Palyankodan variety was 12.56 mg 100^{-1}g. It increased from 12.56 mg 100^{-1}g to 19.25 mg 100^{-1}g and then decreased to 16.99 mg 100^{-1}g on 12^{th} day of storage. The fruits stored under refrigerated cum vacuum showed 13.15 mg 100^{-1}g. The fruits stored under treatments evacuated condition and refrigerated condition showed total carbohydrate content of 15.59 mg 100^{-1} g and 15.86 mg 100^{-1} g respectively.

The lower carbohydrate content in banana packed in polyethylene bags was due to the hydrolysis of starch in to simple sugars. The reduced total carbohydrate content in fruits under refrigerated cum vacuum condition might be due to reduced rate of respiration and water loss from cuticle. These results are comparable to those reported by Fidler and North (1967) for apples and Firmin (1991) for banana.

4.1.5 Total soluble sugars

Data on the total soluble sugars were commonly represented as an index of ripeness. From the Fig. 9 it was found that the total soluble sugar content in Nendran kept as control increased from an initial value of 1.43 mg 100^{-1}g to 16.67 mg 100^{-1}g. then this value decreased to 15.58 mg100^{-1}g within four days, where as in refrigerated cum vacuum condition, Nedran showed very less variation; under this condition, the total soluble sugar increased to 2.28 mg100^{-1}g. The vacuum packed and refrigerated fruits also showed less variation in total soluble sugar content compared to control. These were 3.88 mg100^{-1}g and 4.84 mg100^{-1}g respectively.

Robusta and Palayankodan fruits showed the same trend of variation. The control fruit exhibited total soluble sugar content of 1.20mg 100^{-1}g and this value increased to 17.65 on 8^{th} day of storage and then it decreased to 15.28 at the 12^{th} day of storage. The amount of total soluble sugar increased from 1.20 to 2.67mg for the

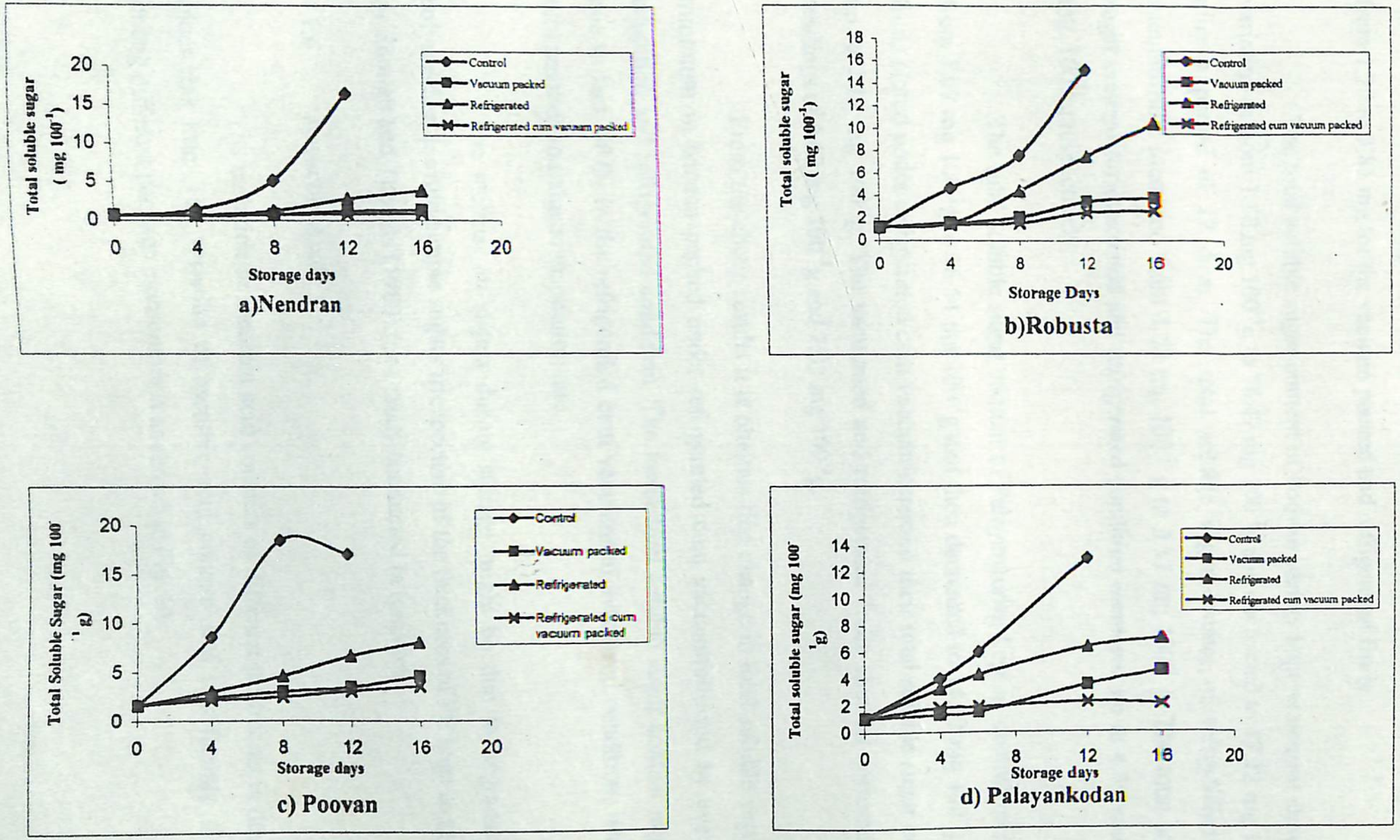


Fig.9 Variation of total soluble sugar with storage period

fruits stored under refrigerated cum vacuumcondition. The total soluble sugar varied from 1.20 to 3.81 mg for the vacuum packed and refrigerated fruits

The total soluble sugar content of Poovan variety kept as control showed a variation in from 1.58 mg 100^{-1}g to 18.47 mg 100^{-1}g and decreased to 17.12 mg 100^{-1}g after a period of 12 days. The total soluble sugar content of refrigerated cum vacuumfruits increased from 1.58 mg 100^{-1} g to 3.57 mg 100^{-1} g. The total soluble sugar content for evacuated and refrigerated condition increased up to 4.59 and 8.06 mg 100^{-1} g respectively.

The total soluble sugar content of Palayankodan kept as control increased from 1.07 mg 100^{-1}g to 16.54 mg 100^{-1}g and then decreased to 14.02 mg 100^{-1}g. The fruits stored under refrigerated cum vacuumincreased their total soluble sugar content up to 2.12 mg 100^{-1}g. The vacuumed and refrigerated fruits showed corresponding readings of 4.62 mg 100^{-1}g and 7.03 mg 100^{-1}g.

From the above results it is obvious that change in total soluble sugar was minimum in banana packed under refrigerated cum vacuumfollowed by evacuated condition and refrigerated condition. The lower total soluble sugar content might be due to lack of O_2 in the refrigerated cum vacuumand evacuated condition, which in turn resulted in reduced respiration rate.

The increase in sugars during storage might be due to degradation of polysaacharides into simple sugars irrespective of the thickness of PE bags as reported by Enough and Thomas (1980) for a study conducted in tomatoes.

4.1.6 Ascorbic Acid

The variation of ascorbic acid contents of different treatments is described under this title. The variation of ascorbic acid content was significantly different among different package environments as shown in Fig.10.

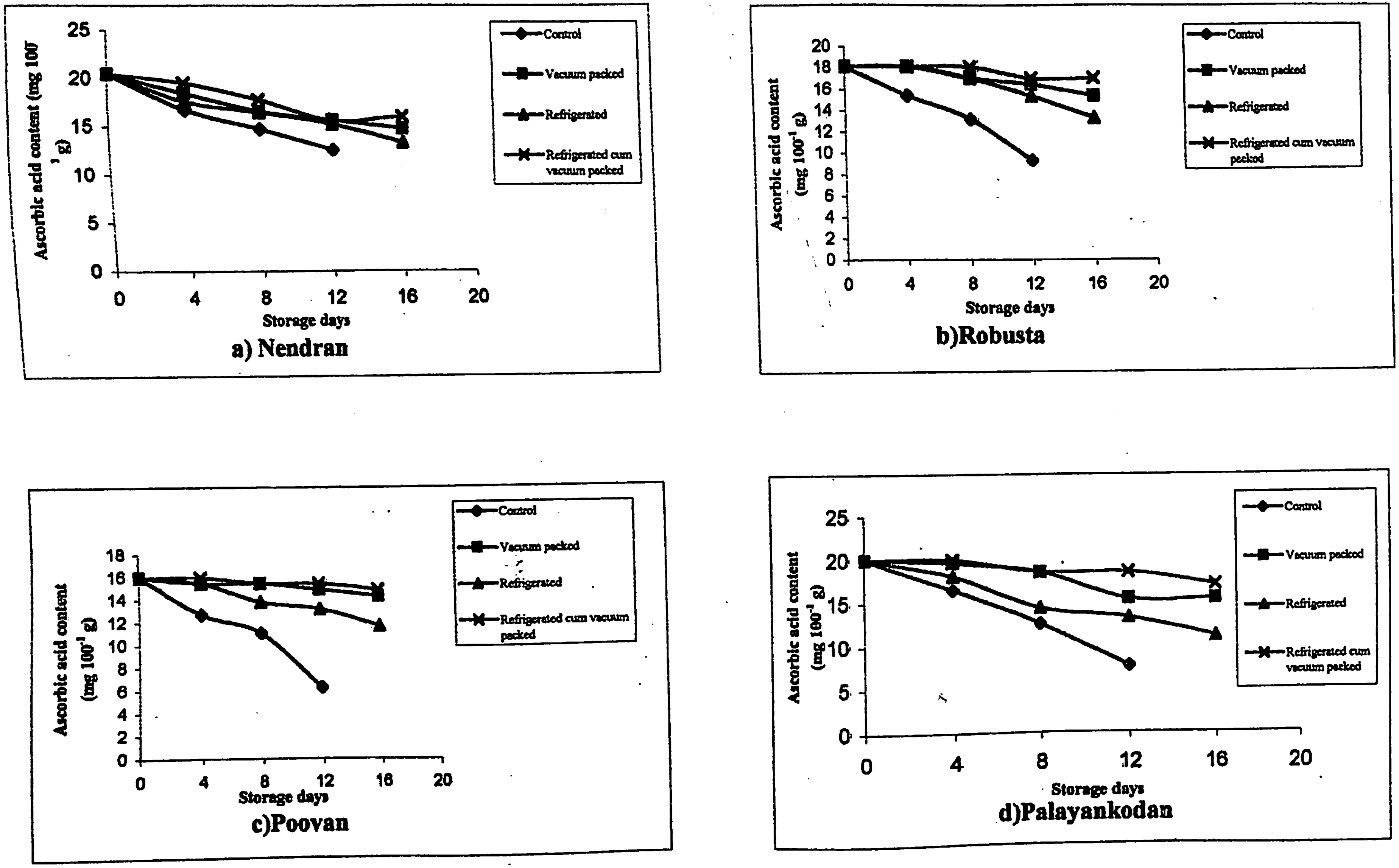


Fig.10 Variation of ascorbic acid content with storage period.

For Nendran variety of fruits, Vitamin C value is maximum (16.01 mg 100^{-1}g) for refrigerated cum vacuumfruits after 16 days of storage.. It was minimum (12.62 mg 100^{-1}g) at the end of the12th day. The initial value of ascorbic acid content was 20.47 mg 100^{-1}g. The ascorbic acid content for fruits stored under vacuum at the end of the 16th day was 14.84 mg 100^{-1}g. For the fruits stored under refrigerated condition, it was 13.37 mg100^{-1}g after the storage of 16 days.

The variation of ascorbic acid content was more rapid in control than any other treatment in case of Robusta banana. The initial value of ascorbic acid content was 18.13 mg100^{-1}g. The maximum value after storage of 16 days (17.06 mg 100^{-1}g) was observed for fruits stored under refrigerated condition. The value decreased from 18.13 mg100^{-1}g to 9.37 mg 100^{-1}g within 12 days in fruits stored open at ambient conditions. The ascorbic acid content decreased 18.13 mg 100^{-1}g to 15.14 mg 100^{-1}g, 13.33 mg 100^{-1}g in vacuum and refrigerated conditions respectively.

Initial ascorbic acid content for Poovan was 16 mg 100^{-1}g. During storage the ascorbic acid content decreased from 16 mg 100^{-1}g to 6.31mg 100^{-1}g in fruits stored under control conditions. For the fruits stored under refrigerated cum vacuumconditions, the reduction of ascorbic acid content was minimum (14.93 mg 100^{-1}g). The fruits stored under vacuum shows 14.34 mg 100^{-1}g ascorbic acid content and refrigerated conditions was 11.74 mg100^{-1}g.

The variation of ascorbic acid content was maximum (from 20.04 mg 100^{-1}g to 7.70 mg 100^{-1}g) after 16 days of storage under control conditions and minimum (20.04 mg 100^{-1} to 17.06 mg 100^{-1}g)for Palayankodan fruits stored under refrigerated cum vacuumconditions after 12 days of storage. The ascorbic acid content for fruits stored under vacuum was 15.47 mg 100^{-1}g and that under refrigerated condition was 11.10 mg 100^{-1}g.

4.1.7 Titrable acidity

The variation of titrable acidity of banana are shown in Fig. 11.

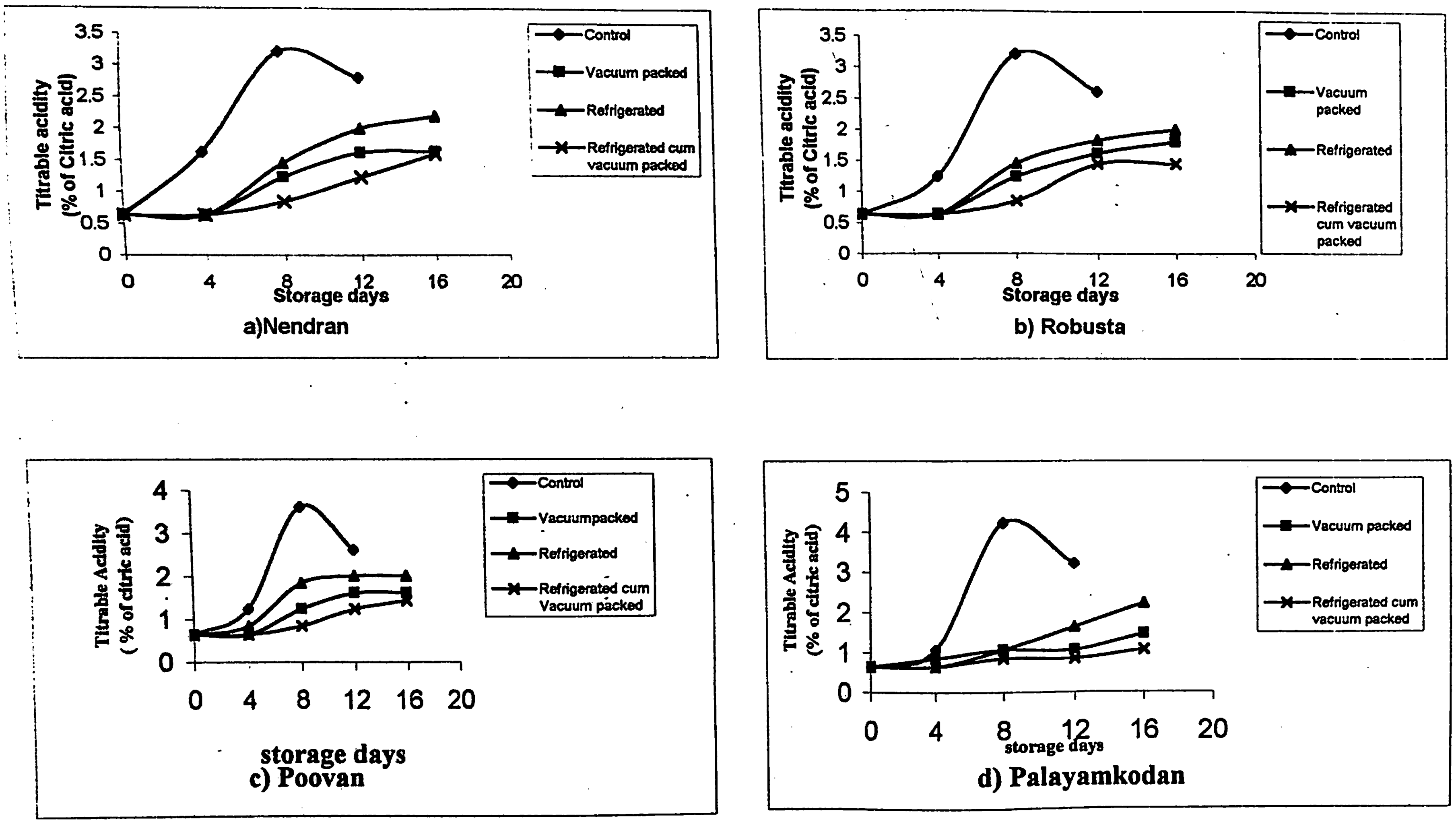


Fig. 11 Variation of titrable acidity with storage period

Nendren variety fruits stored under control showed rapid changes in titrable acidity. It increased from 0.64 to 3.22 % at the 8th day of storage and then decreased to 2.82 after 12th day of storage. The minimum variation of titrable acidity (from 0.64 % to 1.61 %) was obtained for the Nendran fruits stored under refrigerated cum vacuum. For the other two treatments titrable acidity increased from 0.64 to 1.65 % and from 0.64 to 2.21 % respectively for vacuum and refrigerated conditions on the 16th day of storage .

Robusta fruits stored under control (stored open at ambient conditions) showed an increase in titrable acidity from 0.64 to 3.62 % on 8th day of storage and then declined to 2.62 % on 12th day of storage. For all other treatments the titrable acidity increased. Titrable acidity was minimum (1.46 %) for vacuum cum refrigerated. The titrable acidity for vacuum packed Robusta banana after 16 days of storage was observed to be 1.81 % and that of refrigerated storage was found to be 2.02 %.

The titrable acidity of Poovan fruits under control increased from 0.64 % to 3.62 % then declined to 2.61 %. All other treatments showed the same trend as that of Robusta. The titrable acidity of Poovan stored under vacuum after 16 days of storage was 1.61 % and that of refrigerated storage was 2.01 %. The fruits stored under refrigerated cum vacuum was the minimum (1.44 %) after 16 days of storage.

Palayankodan also showed the same trend of variation. Fruits stored under control, exhibited titrable acidity of 4.22 % of citric acid after 8th day of storage and declined to 3.22 % after 12th day.

4.1.8 Microbial spoilage of fruits

The variation of the percentage microbial spoilage of four varieties of banana viz Nendran, Robusta, Poovan and Palayankodan is shown in Appendix VII. From the table it is clear that as the storage period increased the microbial spoilage also increased. Poovan variety was more succeptable to decay as compared to other varieties. This might be due to varietal characteristics like soft skin. The fruits stored under refrigerated condition started ripening after 12th day of storage. Also a dark shade was seen on the fruit surface after 20 days of storage and the fruits were shrivelled. This might be due to chilling injury at low temperature of fruit skin.

The fruits stored under vacuum packing showed firm texture up to 16th day of storage. After 20 days of storage though the fruits were visually firm, the texture was found to be lost. This might be due to CO_2 injury.

4.2 Identification and preparation of products

Banana is a wonder berry, forming an important food supplement for millions. It provides balanced diet than any other fruit or vegetable. The important products from banana are chips, jaggery coated chips, banana powder, jam, jelly, puric etc. Among the above, chips and jaggery coated chips are important items of Kerala feast on special occasions. Banana powder is a natural weaning food for babies from sixth month onwards. Therefore these items were selected for conducting storage studies. The serious problems encountered during storage of chips were rancidity caused by hydrolysis of fats and moisture absorption. The main problem encountered by powder was the effect of caking due to moisture absorption.

4.3 Development of constant temperature frying pan

A constant temperature frying pan was designed, developed and tested as a part of this project is explained under this section.

The calibration curve for constant temperature frying is shown in Fig.12. The temperature of oil at ambient conditions was 32 °C. When the constant temperature frying pan was switched on, the temperature increased rapidly to 105 °C. At the 11th minute banana slices of thickness 1.5 mm was added to coconut oil at temperature 105 °C. The temperature was decreased from 105 to 93 °C. After that temperature increased and reached till 138 °C at the 26th minute. Then salt solution was added and the temperature decreased to 133 °C.

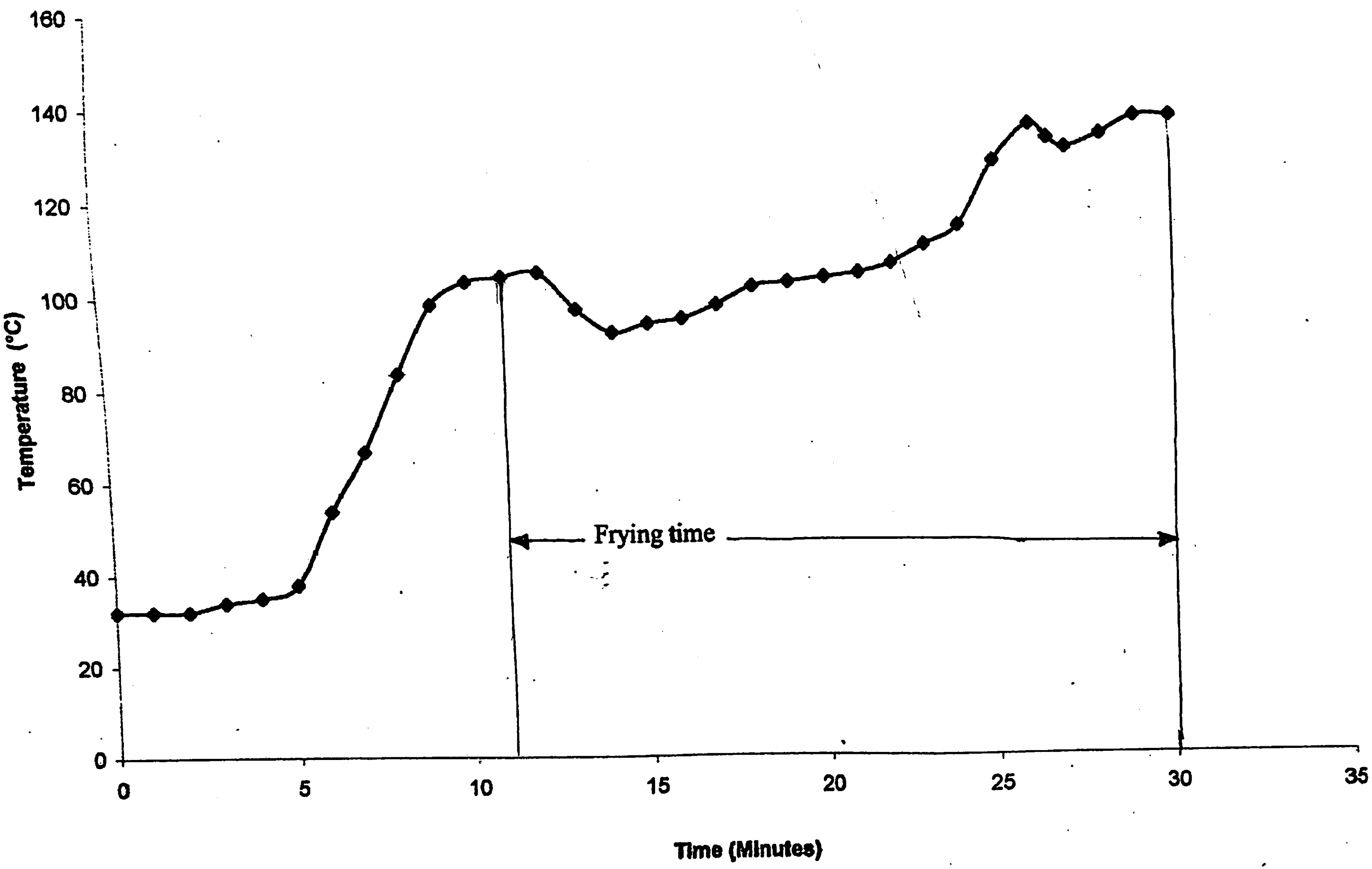


Fig.12 Caliberation Curveof the constant temperature frying pan

The chips fried in coconut oil for a cooking duration of 15 minutes at a temperature of 115 °C was found to be the best. The oil absorption characteristics of the chips are shown in Appendix VII

From this it is seen that at low temperature the absorption of oil is maximum. The factors affecting the extend of fat absorption are (1) length of time of cooking (2) amount of surface area exposed to oil (3) the character and composition of chips.

When the oil is over heated glycerol is dehydrated to acrolein, which is a volatile substance that is highly irritating to mucous membrane. Smoking temperature is an indication of the decomposition of fat.

The time of cooking and temperature of cooking can be controlled by using constant temperature frying pan. The heat losses are very less in constant temperature frying pan so that the labourer can work smoothly.

The chips fried in coconut oil for a cooking period of 15 minutes of a temperature of 115°C was found to be the best from organoleptic analysis.

4.4 Nitrogen packing Set-up

Since the automatic vacuum packaging and gas-flushing machine is of high investment, small-scale industrialists cannot afford to it. By setting up the Nitrogen packing system we can minimize the cost. Hence such a system has been evaluated in this study. The performance evaluation is also shown. The Nitrogen packed food products were seen to be the best compared to other treatments.

The success of Nitrogen packing depends upon initial product quality, appropriate packaging material and equipment and correct gas mixture. Undesirable effects may occur due to higher permeability of packaging material, which may result in inappropriate modification of atmosphere.

Since Nitrogen is inert in ambient conditions, it is used in modified atmosphere packaging system. The nitrogen packing extends transit time, increase in shelf life, reduces economic loss and provides high quality product. The organoleptic evaluation showed that nitrogen packed food had best results for color, texture, taste, flavor and general acceptability for chips and jaggery coated chips of banana.

The acid value of chips was also less in Nitrogen packed foods. The microbial analysis showed that the Nitrogen packed and vacuum packed food products developed very less amount of microbes viz. fungus, bacteria and yeast compared to other treatments. The economics of this kind of a set up is given in the Appendix VIII

4.5 Storage of Products

The study was conducted by packing the products under different package environments in polyethylene bags and stored at room temperature (RT).

The effect of different package environments on various characteristics of banana products is discussed below.

4.5.1 Banana Chips

Quality changes during storage of banana chips are discussed here under the following headings

4.5.1.1 Moisture content

The moisture content variations after storage for two months are furnished in Table 3

From it is noted that the chips fried in coconut oil at 115 °C for 20 minutes ($O_1T_3D_3$) is having less moisture content with an initial moisture content 0.91 %. The minimum content was found to be for chips stored under nitrogen packing and it was prepared in coconut oil at a temperature 115 °C for a duration 20 minutes (1.28 %).

The lower initial moisture content may be due to high temperature and long duration frying. As the cooking time increases moisture content decreases and as the temperature of cooking increases also moisture content decreases.

From the interaction between moisture content and package environment, Nitrogen packing and vacuum packing reduced rapid increase in moisture content. This might be due to low water vapour transmission through the packaging material. The increase in moisture content was proportional to storage period. The same is also observed by Balasubhrahmanyam and Anandaswamy (1979) for fried potato chips and Sagar *et al.* (1998) for dried mango slices.

Table 3. Variation of moisture content of chips

Treatment	Initial	Moisture after two weeks	Content after four weeks	After six weeks	After eight weeks
$O_1T_2D_2$ C	1.15	1.23	1.74	2.19	2.93
$O_1T_2D_2$ A	,,	1.20	1.63	2.94	2.46
$O_1T_2D_2$ V	,,	1.15	1.28	1.35	1.60
$O_1T_2D_2$ N	,,	1.15	1.23	1.34	1.38
$O_1T_2D_3$ C	1.09	1.17	1.72	1.93	2.67
$O_1T_2D_3$ A	,,	1.13	1.69	1.79	1.88
$O_1T_2D_3$ V	,,	1.10	1.15	1.27	1.37
$O_1T_2D_3$ N	,,	1.10	1.15	1.27	1.37
$O_1T_3D_2$ C	0.91	1.14	1.68	1.86	2.45
$O_1T_3D_2$ A	,,	1.08	1.45	1.72	1.82
$O_1T_3D_2$ V	,,	0.99	1.08	1.16	1.32
$O_1T_3D_2$ N	,,	0.99	1.03	1.13	1.28
$O_1T_3D_2$ C	1.07	1.16	1.38	1.62	2.56
$O_1T_3D_2$ A	,,	1.13	1.24	1.48	2.01
$O_1T_3D_2$ V	,,	1.09	1.16	1.23	1.43
$O_1T_3D_2$ N	,,	1.09	1.15	1.20	1.37
$O_1T_3D_3$ C	1.03	1.16	1.54	2.08	2.58
$O_1T_3D_3$ A	,,	1.11	1.50	1.82	1.98
$O_1T_3D_3$ V	,,	1.03	1.14	1.22	1.36
$O_1T_3D_3$ N	,,	1.04	1.09	1.21	1.33
$O_1T_4D_2$ C	1.14	1.19	1.23	1.58	2.65
$O_1T_4D_2$ A	,,	1.18	1.20	1.45	1.79
$O_1T_4D_2$ V	,,	1.16	1.24	1.30	1.42
$O_1T_4D_2$ N	,,	1.15	1.20	1.26	1.38

4.5.1.2 Rancidity

The rancidity of chips during storage is given in terms of acid value in Table 4. Considering the interaction between temperature and acid value, it is evident that as the temperature increases the acid value also increases. The increased acid value may be the cause of rancidity.

Further, high fat content and large surface area of the product exhibited a serious problem of rancidity. Light and oxygen enhance the rate of deterioration and this is further accelerated by temperature, presence of metals like copper and radiation by UV rays (Balasubrahmanyan and Anandaswamy, 1979). Rancidity is caused by spoilage of fats due to chemical changes. The theory of rancidity suggests that addition of oxygen to carbon atoms next to a double bond in a fatty acid chain results in formation of a product called hydroperoxide. Hydroperoxides themselves do not appear to have unpleasant rancid odours of rancid flavour, but these molecules readily break in to pieces, producing smaller volatile substances that give the characteristic odours of rancid fat. It is a chain reaction that is self perpetuating. Therefore, once a fat develops a slight rancid odour, it grows to more pronounced rancidity rapidly.

4.5.1.3 Microbial spoilage of chips

The microbial spoilage of chips after two months were recorded as the total count of fungal and bacterial growth. The results are tabulated in Table 5 The results indicate that in vacuum packed and Nitrogen packed chips microbial count is very less compared to control and air packing. The microbial count was very less in vacuum and Nitrogen packing after two months storage. This may be due to low moisture content of chips contained in vacuum and Nitrogen packing. Also this may be due to absence of Oxygen for the growth of microbes.

Table 4. Variation of acid value of chips

Treatment	Initial	Moisture after two weeks	Content after four weeks	After six weeks	After eight weeks
$O_1T_2D_2$ C	2.62	2.74	3.49	4.67	6.83
$O_1T_2D_2$ A	"	2.82	2.34	3.94	4.68
$O_1T_2D_2$ V	"	2.73	3.68	3.68	4.19
$O_1T_2D_2$ N	"	2.72	3.04	3.54	3.96
$O_1T_2D_3$ C	2.63	2.85	3.18	4.35	5.23
$O_1T_2D_3$ A	"	2.63	2.96	3.49	3.95
$O_1T_2D_3$ V	"	2.75	2.96	3.36	3.78
$O_1T_3D_2$ C	2.67	2.73	3.05	4.16	5.17
$O_1T_3D_2$ A	"	2.72	3.04	3.96	5.06
$O_1T_3D_2$ V	"	2.75	2.85	3.06	3.37
$O_1T_3D_2$ N	"	2.68	2.91	3.18	3.36
$O_1T_3D_3$ C	2.74	2.78	3.86	4.28	5.33
$O_1T_3D_3$ A	"	2.76	3.09	4.16	5.02
$O_1T_3D_3$ V	"	2.76	2.86	3.14	3.58
$O_1T_3D_3$ N	"	2.78	2.84	3.08	3.47
$O_1T_4D_2$ C	2.69	2.86	3.45	4.38	5.04
$O_1T_4D_2$ A	"	2.84	3.37	4.25	4.93
$O_1T_4D_2$ V	"	2.73	3.13	3.19	3.75
$O_1T_4D_2$ N	"	2.74	2.94	3.14	3.46
$O_1T_3D_2$ C	2.68	3.37	4.56	5.78	6.68
$O_1T_3D_2$ A	"	3.24	4.03	4.84	5.96
$O_1T_3D_2$ V	"	2.65	2.68	3.57	4.34
$O_1T_3D_2$ N	"	2.78	3.35	3.67	4.28

Table 5. Microbial spoilage of chips

Treatment	Bacteria x 10^6	Fungus x 10^4
$O_1T_2D_2$ C	7.00	7.33
$O_1T_2D_2$ A	3.33	2.69
$O_1T_2D_2$ V	0.67	0.67
$O_1T_2D_2$ N	0.33	0.33
$O_1T_2D_3$ C	6.33	6.67
$O_1T_2D_3$ A	2.67	2.33
$O_1T_2D_3$ V	0.33	0.33
$O_1T_2D_3$ N	0	0
$O_1T_3D_2$ C	6.00	6.67
$O_1T_3D_2$ A	2.33	2.33
$O_1T_3D_2$ V	0	0.33
$O_1T_3D_2$ N	0	0.33
$O_1T_3D_3$ C	6.67	7.33
$O_1T_3D_3$ A	0.67	1.00
$O_1T_3D_3$ V	0.67	0.67
$O_1T_3D_3$ N	0.33	0.33
$O_1T_4D_2$ C	7.33	6.67
$O_1T_4D_2$ A	2.67	2.67
$O_1T_4D_2$ V	0.67	0.67
$O_1T_4D_2$ N	0.33	0.33
$O_2T_3D_2$ C	6.67	6.67
$O_2T_3D_2$ A	2.67	3.33
$O_2T_3D_2$ V	0.33	0.67
$O_2T_3D_2$ N	0.33	0.33

4.5.1.4 Equilibrium Relative Humidity studies of chips

Results of ERH studies is shown in Table 6 and humidity moisture equilibrium curve is shown in Fig.13. The product equilibrated to RH of 32 % and 43 % are acceptable with an equilibrium moisture content of 2.14 % and 3.49 % respectively. Product exposed to 75 % RH and above was having high EMC values and was organoleptically unacceptable. The critical value for chips was found as 6 % EMC corresponding to 71 % RH. The danger point is that having relative humidity 5 % less than that of critical point. The danger point obtained was at 5.7 % EMC. Moisture level of about 5.7 % would be the safe limit with respect to organoleptic acceptability of product from the point of crispness.

Table.6 ERH properties of banana chips

Equilibrium Moisture content (%)	Equilibrium Relative Humidity (%)	No. of days to reach equilibrium	Remarks
2.14	32	26	Good texture, color and flavour
3.49	43	20	Good texture, color and flavour
14.14	75	16	Soft ,color normal
24.64	80	136	Very soft ,Mould growth started after 21 days
32.83	90	10	Mould growth started after 13 days
44.65	97	8	Mould growth started after 7 days

4.5.1.5 Organoleptic properties

The mean value of the organoleptic scores obtained while evaluating storage properties of chips are furnished in Tables 7,8 and 9.

From Tables 7, 8 and 9 it is clear that colour do not vary significantly among treatments and packaging methods.

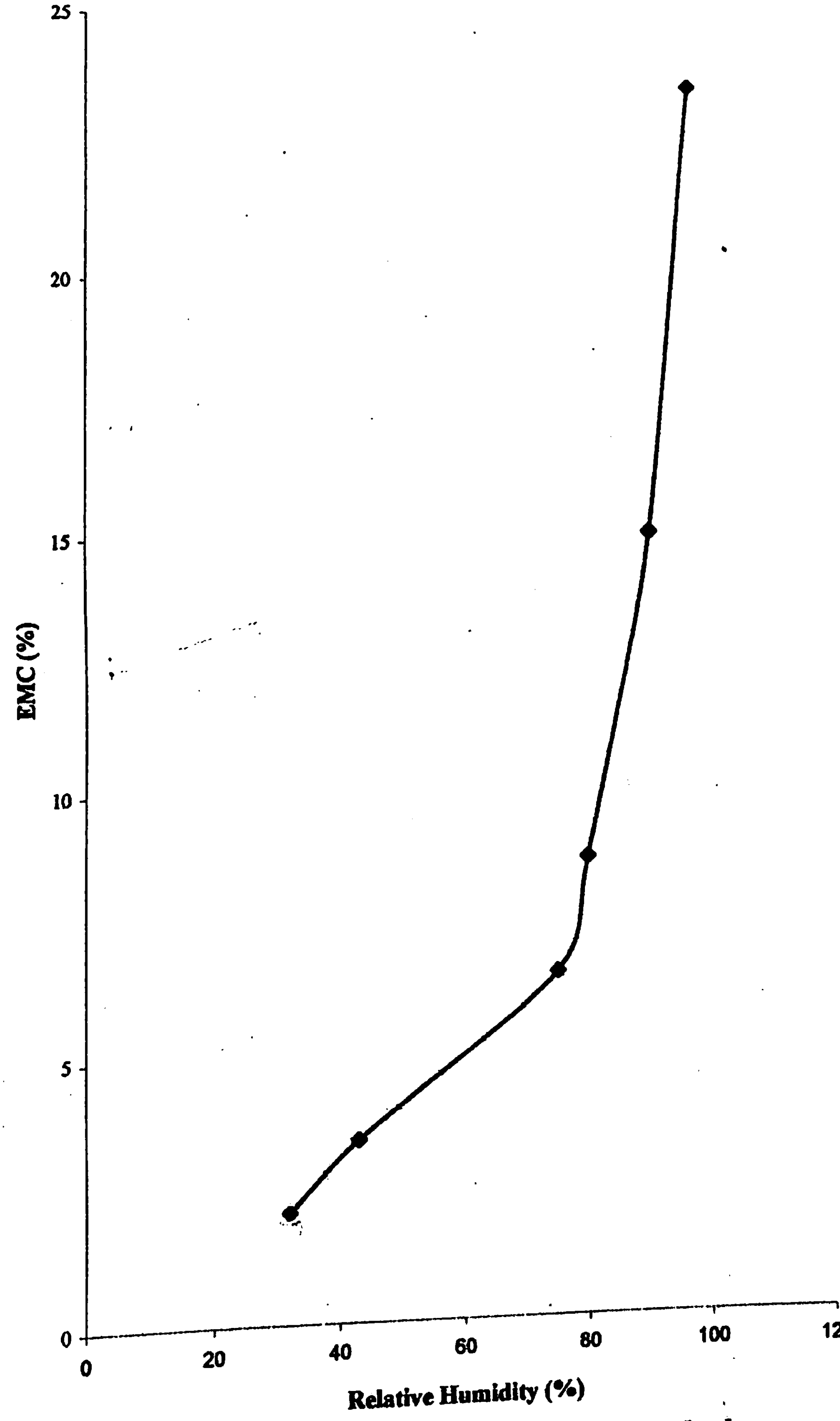


Fig.13 Relative Humidity- Moisture curve for banana chips

Table 7. Mean values of the organoleptic scores obtained for different temperature treatments of banana chips

Treatment	Color	Texture	Taste	Flavour	General Acceptability
$O_1T_2D_2$	7.48	7.33	6.88	6.54	6.41
$O_1T_2D_3$	7.48	7.45	7.4	7.19	6.75
$O_1T_3D_2$	7.44	7.32	7.4	7.13	6.87
$O_1T_3D_3$	7.55	7.28	7.12	7.04	6.59
$O_1T_4D_2$	7.34	6.92	7.03	6.84	6.51
$O_2T_3D_2$	7.52	6.97	7.07	6.76	6.69

Table 8. Mean values of the organoleptic scores obtained for different packaging treatments of banana chips

Packaging treatment	Color	Texture	Taste	Flavour	General Acceptability
Control	7.45	6.81	6.88	6.34	6.60
Air packing	7.48	7.04	7.13	6.86	6.30
Vacuum packaging	7.48	7.50	7.39	7.13	7.04
Nitrogen packaging	7.48	7.50	7.40	7.34	7.20

Chips prepared in coconut oil at a temperature 105 °C for 20 minutes secured highest score for texture. Among the packaging treatment vacuum and nitrogen pakaging secured highest score. Considering the combination of the two, chips prepared in coconut oil at a temperature 105 °C for 20 min. kept under nitrogen packing (mean score 7.7) was found to be the best.

From the organoleptic score obtained for taste it was found that the best treatment was frying banana slices in coconut oil at a temperature 105 °C for 20 min. Among the four packaging methods mentioned nitrogen packing secured highest score for taste.when the combinaton of treatments and packaging are considered chips fried in coconut oil at a temperature 115 °C for 15 min. kept under nitrogen packing was found to be the best.

The chips fried in coconut oil at a temperature 115 °C for 15 min was found to be the best with regard to flavour retaining. Considering the packaging treatment vacuum packaging was the best retaining flavour .The chips fried in coconut oil at a temperature 105 °C for 20 min. stored under nitrogen packing was found to the best for retention of flavour while considering the treatment combinations.

Table 9. Mean values of the organoleptic scores obtained for different treatment combinations of chips

Treatment combination	Color	Texture	Taste	Flavour	General Acceptability
$O_1T_2D_2$ C	7.45	7.08	6.88	6.25	6.03
$O_1T_2D_2$ A	7.50	7.28	7.15	6.35	6.25
$O_1T_2D_2$ V	7.45	7.50	7.40	6.50	6.35
$O_1T_2D_2$ N	7.50	7.45	7.40	7.05	7.00
$O_1T_2D_3$ C	7.48	7.08	7.03	6.6	6.18
$O_1T_2D_3$ A	7.45	7.35	7.07	7.15	6.25
$O_1T_2D_3$ V	7.48	7.70	7.68	7.40	7.30
$O_1T_2D_3$ N	7.50	7.65	7.92	7.60	7.30
$O_1T_3D_2$ C	7.35	6.88	7.45	6.73	6.18
$O_1T_3D_2$ A	7.60	7.15	7.48	7.05	6.45
$O_1T_3D_2$ V	7.43	7.10	8.05	7.30	7.40
$O_1T_3D_2$ N	7.40	7.65	8.10	7.45	7.45
$O_1T_3D_3$ C	7.60	6.83	6.8	6.48	5.93
$O_1T_3D_3$ A	7.55	7.10	7.10	7.13	6.30
$O_1T_3D_3$ V	7.53	7.60	7.65	7.25	7.03
$O_1T_3D_3$ N	7.55	7.60	7.93	7.35	7.10
$O_1T_4D_2$ C	7.35	6.58	7.07	6.13	5.73
$O_1T_4D_2$ A	7.35	6.70	6.85	6.90	6.10
$O_1T_4D_2$ V	7.35	7.18	7.82	7.15	7.05
$O_1T_4D_2$ N	7.33	7.22	7.85	7.20	7.18
$O_2T_3D_2$ C	7.48	6.45	6.75	5.88	5.98
$O_2T_3D_2$ A	7.40	6.62	6.90	6.58	6.48
$O_2T_3D_2$ V	7.63	7.40	7.70	6.80	7.10
$O_2T_3D_2$ N	7.63	7.40	7.80	6.90	7.20

Considering the property of general acceptability of banana chips frying in coconut oil at a temperature115 °C for 15 min. was found to be the best. Among the packaging environments nitrogen packing secured maximum score for general acceptability .The nitrogen packed banana chips from coconut oil at a temperature 115 °C for 15 min was found to be the best when the treatment combinations were is considered under the property general acceptability.

In this study the property general acceptability was used to find out the best treatment combination. The chips fried in coconut oil at a temperature of 115 °C for 15 minutes could successfully stored under nitrogen packing up to two months with out any organoleptic change.

4.5.2 Jaggery coated chips

The results of the experiments to evaluate storage characteristics of jaggery coated chips are discussed here under.

4.5.2.1 Moisture content

The initial moisture content for jaggery coated chips was found to be 1.25 %.

From Table 10 it is clear that the moisture content increased from 1.25 % to 1.84 % in case of 'control', 1.52 % in case of air packing, 1.32 % in case of vacuum packing and 1.29 % in case of nitrogen packing. From these results it is inferred that moisture accumulation was more in control compared to any other treatments. The minimum moisture accumulation was found in nitrogen packed, jaggery - coated chips.

The lower moisture content in jaggery coated chips was due to low permeability of packaging material and absence of moisture inside the packet in case of vacuum packed and nitrogen packed jaggery coated chips.

Table 10. Variation of moisture content for jaggery coated chips.

Treatment	Initial	After two weeks	After four weeks	After six weeks	After eight weeks
Control	1.25	1.28	1.32	1.54	1.84
Air packing	,,	1.28	1.30	1.41	1.52
Vacuum packing	,,	1.25	1.27	1.29	1.32
Nitrogen packing	,,	1.25	1.26	1.27	1.29

4.5.2.2 Microbial spoilage of Jaggery coated chips

The microbial spoilage of jaggery coated chips are described in Table 11

From the table it is observed that the microbial counts in vacuum packing and nitrogen packing were much lower than other treatments. The bacterial count for control was 7 x 10^6 and those for nitrogen packing and vacuum packing were 1 x 10^6, 1.33 x 10^6 respectively. The fungal spoilage of control amounts to 3.3 x 10^4 and that for air packing. vacuum packing and nitrogen packing was found to be 1.67 x 10^4, 1 x 10^4 and 1.33 x 10^4 respectively. The yeast count for control was found to be 2.33 x 10^4 and that for air packing, vacuum packing and nitrogen packing were1.52 x10^4, 1.32 x 10^4 and 1 x 10^4.

Table 11. Microbial spoilage of jaggery coated chips

Treatment	Bacteria x 10^6	Fungus x 10^4	Yeast x 10^4
Control	7.00	3.33	2.33
Air packing	1.67	1.67	1.67
Vacuum packing	1.33	1.00	1.33
Nitrogen packing	1.00	1.33	1.00

4.5.2.3 ERH studies of Jaggery coated chips

The data regarding ERH of jaggery coated banana chips are presented in Table 12 and the humidity-moisture equilibrium curve is shown in Fig.14. The product retained its quality with respect to colour, taste, flavour, texture and overall acceptability up to 9.93 % EMC. When the product is exposed to 80 % RH, the EMC value was 11.34 % and the product losses crispness and the mould growth started after 22 days. The critical point was found to be at 8 % EMC and corresponding ERH was 67.5 %. The danger point was found at 6.4 % EMC corresponding to ERH 57 %.

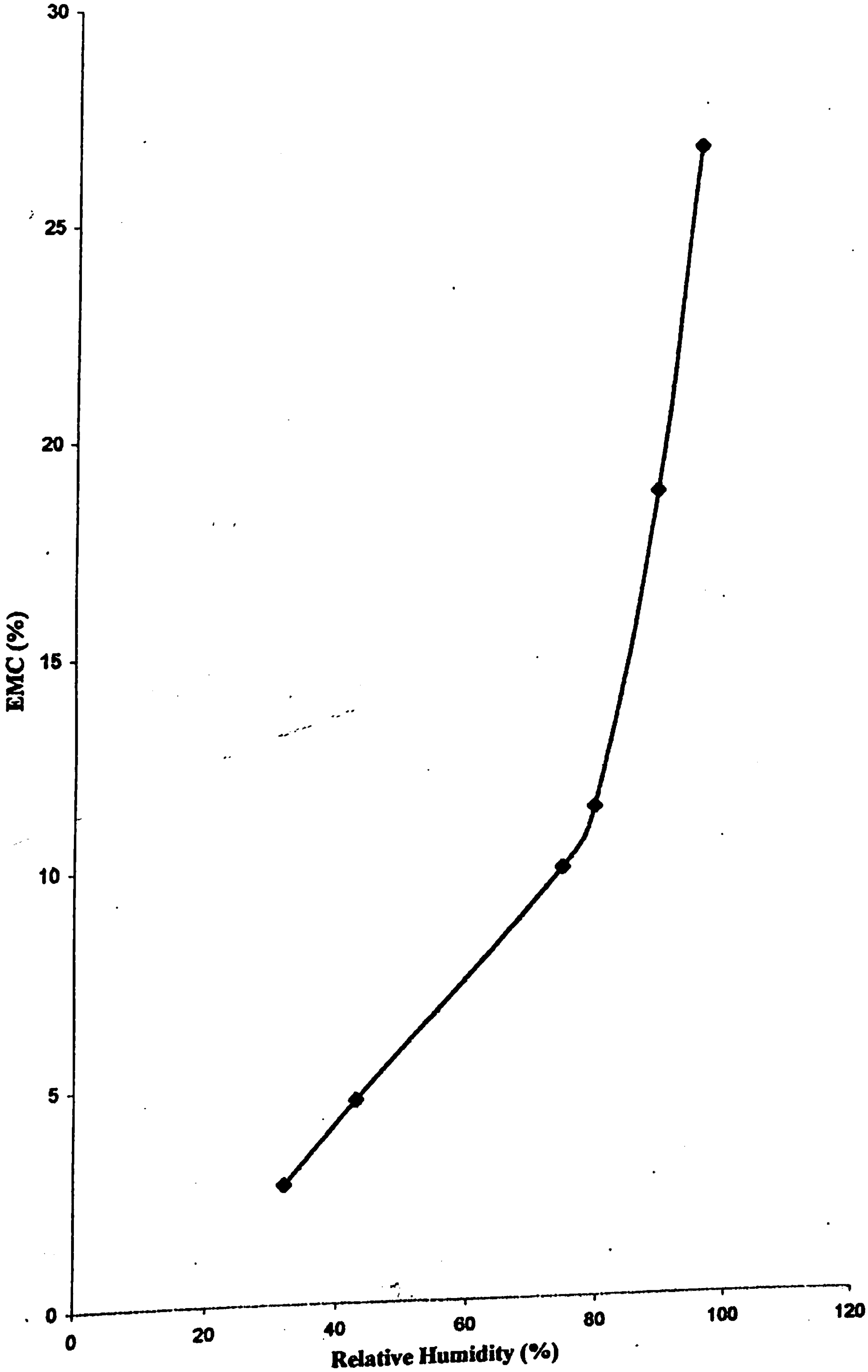


Fig.14 Relative Humidity - Moisture curve for Jaggery coated chips

Table .1 ERH properties of jaggery coated chips

Equilibrium moisture content (%)	Equilibrium Relative Humidity (%)	No. of days to reach equilibrium	Remarks
2.83	32	33	No change
4.67	43	24	No change
9.93	75	20	Nochange
11.34	80	15	Taste differs, mould growth started after 22 days
18.76	90	12	Mould growth started after 15 days
26.94	97	9	Mould growth started after 9 days

4.5.2.4 Organoleptic properties

The details of the organoleptic scores obtained for jaggery coated chips after two months of storage is shown in Table 13

From the organoleptic scores obtained, it is found that different packaging environments do not effect the organoleptic properties significantly after two months storage. However nitrogen packed jaggery coated chips secured maximum score for texture and flavour. Vacuum packed and nitrogen packed jaggery coated chips secured a maximum score of 7.45 for taste and general acceptability. Jaggery coated chips can be stored up to two months under vacuum and nitrogen packing with out any organoleptic change.

Table 13 Mean values of organoleptic scores obtained for jaggery coated chips

Packaging Treatment	Color	Texture	Taste	Flavour	General acceptability
Control	7.30	7.30	6.8	7.20	7.00
Air packing	7.30	7.38	7.1	7.30	7.25
Vacuum packing	7.30	7.45	7.45	7.40	7.45
Nitrogen packing	7.28	7.45	7.45	7.45	7.45

4.5.3 Powder

The results of the experiments conducted to evaluate the storage properties of powder are presented below.

4.5.3.1 Moisture content

The variation of moisture content in banana powder under storage is tabulated in Table 14. The initial moisture content was found to be 1.21 %. The moisture content was maximum after two months storage under control as compared to the other treatments. The nitrogen packing and vacuum packing have less amount of moisture present in it.

The low moisture content might be due to the absence of atmospheric air containing moisture inside the packet and low water vapour transmission of the packet. The same pattern of variation was reported by Sagar and Roy (1997) for potato powder.

Table 14 Variation of moisture content for powder

Treatment	Initial	After two weeks	After four weeks	After six weeks	After eight weeks
Control	1.21	1.38	1.45	2.64	3.27
Air packing	"	1.25	1.38	2.37	2.54
Vacuum packing	"	1.23	1.34	1.45	1.98
Nitrogen packing	"	1.22	1.37	1.42	1.87

4.5.2 Sulphur dioxide content

The change in sulphur dioxide content during storage of banana powder was tabulated in Table 15. The initial sulphur dioxide content was found to be 433 ppm. For all the treatment, the sulphur dioxide content was found to be reducing during storage.

Table 15. Variation of sulphur dioxide of banana powder

Initial SO_2 content : 433 ppm

Treatment	After two weeks	After four weeks	After six weeks	After eight weeks
Control	426	402	385	324
Air packing	430	418	397	378
Vaccum packing	433	424	416	404
Nitrogen packing	432	427	423	420

4.5.3.3 Non-enzymatic browning

The readings of the non-enzymatic browning are tabulated in the Table 16. From the table, it is clear that the non-enzymatic browning varied with respect to different environmental packages. In control, the non-enzymatic browning increased from 0.125 to 0.295 where as in the nitrogen packing the observed value after two months storage is only 0.149;. i.e., the change in non-enzymatic browning of banana powder was very less in nitrogen packing. In air packing the non-enzymatic browning increased from 0.125 to 0.206 and in vacuum packing it increased from 0.125 to 0.135.

The discolouration of banana powder was due to non-enzymatic browning caused by Maillard reaction and ascorbic acid browning. Presence of oxygen accelerates the above reaction and causes browning. The non-enzymatic browning was more in samples stored at control and air packing conditions at room temperatures. This could be due to high oxygen content and inadequate SO_2 level in the powders packed in control and air packed samples. Balasubrahmanyam and Anandaswamy (1979) observed similar trends in this kind of study.

The rate of increase in browning was inversely proportional to sulphur dioxide content. This is in conformity with the findings of Sagar and Roy (1997).

4.5.3.4 Microbial analysis of powder

Table 17 shows the microbial spoilage of banana powder in terms of total count of bacteria and fungal pathogens. From the table it is obvious that the vacuum packed and nitrogen packed powder had less spoilage. The bacterial count in banana powder after a storage of two months was found to be 6 x 10^6 whereas the vacuum packing and nitrogen packing showed 1.33 x 10^6 and 1.33 x 10^6 respectively. The total count of fungal pathogens in control was found to be 6 x 10^4 whereas in vacuum packing and nitrogen packing these were 1.33 x10^4 and 2.0 x 10^4 respectively.

Table 16. Variation of non-enzymatic browning of powder

Initial Non-enzymatic browning : 0.125

Treatment	After two weeks	After four weeks	After six weeks	After eight weeks
Control	0.181	0.132	0.134	0.128
Air packing	0.295	0.206	0.135	0.127
Vacuum packing	0.537	0.295	0.140	0.128
Nitrogen packing	0.624	0.424	0.156	0.135

The lower count of microbes may attributed to the fact of absence of oxygen inside the packages and low water vapour permeability of the packages.

Table 17. Variation of microbial spoilage of banana powder after two months storage

Treatment	Bacteria (x 10^6)	Fungus (x 10^4)
Control	6.00	6.00
Air packing	2.67	3.67
Vacuum packing	1.33	1.33
Nitrogen packing	1.33	2.00

4.5.3.5 ERH studies

The data regarding ERH of banana powder is presented in Table 18 and humidity-moisture equilibrium curve is shown in Fig. 15. The product retained its quality with respect to colour, texture and overall acceptability even after two months storage. When the product was exposed to 75 % RH the EMC value was 18.94 % the product became lumpy and hence unacceptable. Mould growth started at 22.57 % EMC after 7 days. However the critical point was 5.3 % and the corresponding ERH was 46 %. The optimum relative humidity for banana powder is 75 % when initial moisture content is 1.21 %.

Table 18. Relative Humidity - Moisture content characteristics of banana powder

Equilibrium moisture content (%)	Relative Humidity (%)	Days to achieve equilibrium	Remarks
2.96	32		Colour normal
4.73	43	12	Colour normal
18.94	75	10	Colour normal, caking started after 5 days
22.57	80	9	Yellow colour, caking started after 3 days, mould growth after 7 days
34.65	90	7	Yellow colour, caking started after 2 days, mould growth after 5 days
47.62	97	5	Caking started after 2 days, mould growth after 3 days

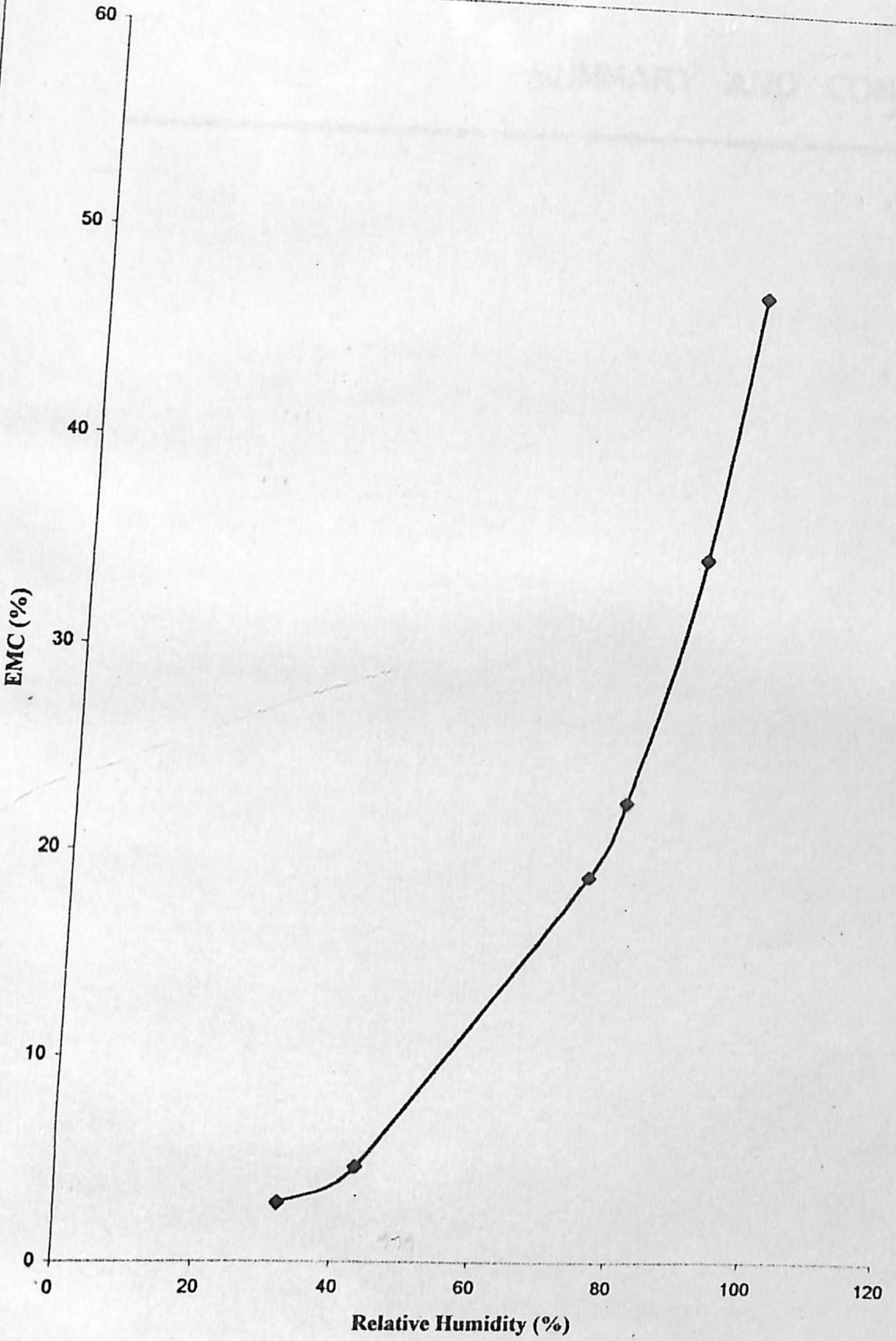


Fig.15 Relative Humidity -Moisture curve for banana powder

SUMMARY AND CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSION

Banana is a wonder berry, forming an important food supplement for millions. It provides a balanced diet than any other fruit or vegetable. There are about 60 varieties of banana grown in India. But only a dozen are of commercial importance in Kerala namely Nendran, Robusta, Poovan and Palayankodan. So these products are selected for conducting storage studies.

In Kerala, during peak season the farmers sell the different varieties of fruit directly to the market. High fruit yield will be worthwhile only if the product reach the consumer in sound condition. Banana fruits begin to lose their orchard freshness shortly after they are plucked from the tree. These losses are due to the factors such as rapid ripening, high respiration and transpiration, microbial spoilage, lack of proper storage facilities etc. The post harvest losses can be minimized by adoption of modern storage and handling facilities and technologies with special emphasis on proper packaging and conversion of produce in to value added products.

Banana chips, puree, figs, soft drinks, powder, jam, confectionary, dehydrated core slices are the main products of banana. Nendran chips, jaggery coated chips and powder are of special interest to Kerala context. Therefore these products are selected for conducting this study.

Four varieties of banana viz. Nendran, Robusta, Poovan and Palayankodan were stored under four conditions. Control (stored open at ambient conditions), vacuum packing, refrigerated and refrigerated cum vacuum packing. Quality changes were observed for physical, chemical and microbial parameters. Among the four treatments refrigerated cum vacuum packed fruits showed less quality deterioration with respects physical, chemical and microbial changes. The control fruits of all the varieties decayed within 7 days of storage. Vacuum packed fruits remained fresh up to 12 days and after a 16th day of storage these were visually firm lost their texture.

Banana stored under refrigeration experienced a black spread on the surface of banana due to chilling injury. Further storage resulted in shrivelling of skin and loss of core texture. The refrigerated cum vacuum packed fruits remained best even after 20th day of storage because it was protected from chilling injury by the thickness of polyethylene film and retarded ripening and respiration by low temperature.

For optimizing the thermal and physical processing conditions, a constant temperature frying pan was developed. The frying pan has provision to control oil temperature. The size of the frying pan is 45 cm dia and 15 cm depth. The cylindrical heating chamber had 35 cm dia and 20 cm height. The calibration curve was also plotted connecting temperature and cooking time.

The chips were fried in constant temperature frying pan at four different temperatures (95, 105, 115 and 125 °C) for four durations (10, 15, 20 and 25 min) by using three different oils (coconut, palm and sunflower oil). After the preparation of chips all the samples were organoleptically evaluated studies. The chips tried in sunflower oil was eliminated during this experiments because it secured very low organoleptic score.

Six samples were selected and the samples were exposed to four different type of packages. From the organoleptic analysis, after two month storage it was found that the chips fried in coconut oil at a temperature 115 °C for a duration of 15 min. and kept under nitrogen packing was found to be the best followed by chips fried in coconut oil at a temperature 115 °C for 15 min and kept under vacuum packing. The chips fried in palm oil was found to be little brittle compared to other treatments.

From quality analysis it was found that nitrogen packed and vacuum packed chips undergone very less quality deterioration compared to control and air packed chips.

A low cost set-up was developed nitrogen packing. The set-up consists of vacuum pump, nitrogen cylinder and pipe lines with control valves. The system worked satisfactorily for nitrogen packing as well as for vacuum packing.

The major problem encountered during the storage of chips and other products were rancidity and moisture absorption of unsaturated fatty acids. Rancidity was caused by oxidation and hydrolysis of fats.

The rate of these reactions were lowered due to absence of oxygen inside the packages. As the quantity of moisture absorbed by the products increased the chips lost crispness and the powder became lumpy. Modification of the atmosphere surrounding the products also retards the rate of moisture absorption and this reduces the infection by microbes. Hence the study brought out following the conclusions.

1. Vacuum cum refrigerated packing extended the shelf life of banana fruits up to 20 days without any quality deterioration. The vacuum packed fruits could be stored up to 12 days with out any quality deterioration using no chemicals or fungicides at ambient conditions. storage of fruits under refrigeration results in chilling injury.
2. The constant temperature frying pan developed satisfactorily at all temperatures tested. The capacity of constant temperature frying pan was 100 kg/day of raw banana.
3. The chips fried in coconut oil at a temperature of 115 °C for a duration of 15 min stored under nitrogen packing gave best result after storage for two months on the basis of organoleptic evaluation.
4. The low cost set up developed for nitrogen packing shall be adaptable for vacuum packing and nitrogen packing and the results are satisfactory.
5. The shelf life studies of banana products revealed that the products stored under nitrogen packing and vacuum packing have no significant difference on the basis of organoleptic evaluation. However, the products stored under nitrogen packing remained best on the basis of general acceptability.
6. The economic analysis showed that the cost of entire processing of one kilogram of banana chips was Rs.57.5.

The moisture content of raw banana have considerable effect on frying time. Therefore the moisture content of the banana slices used for chips making need be standardized. The peeling and slicing operations were done manually.

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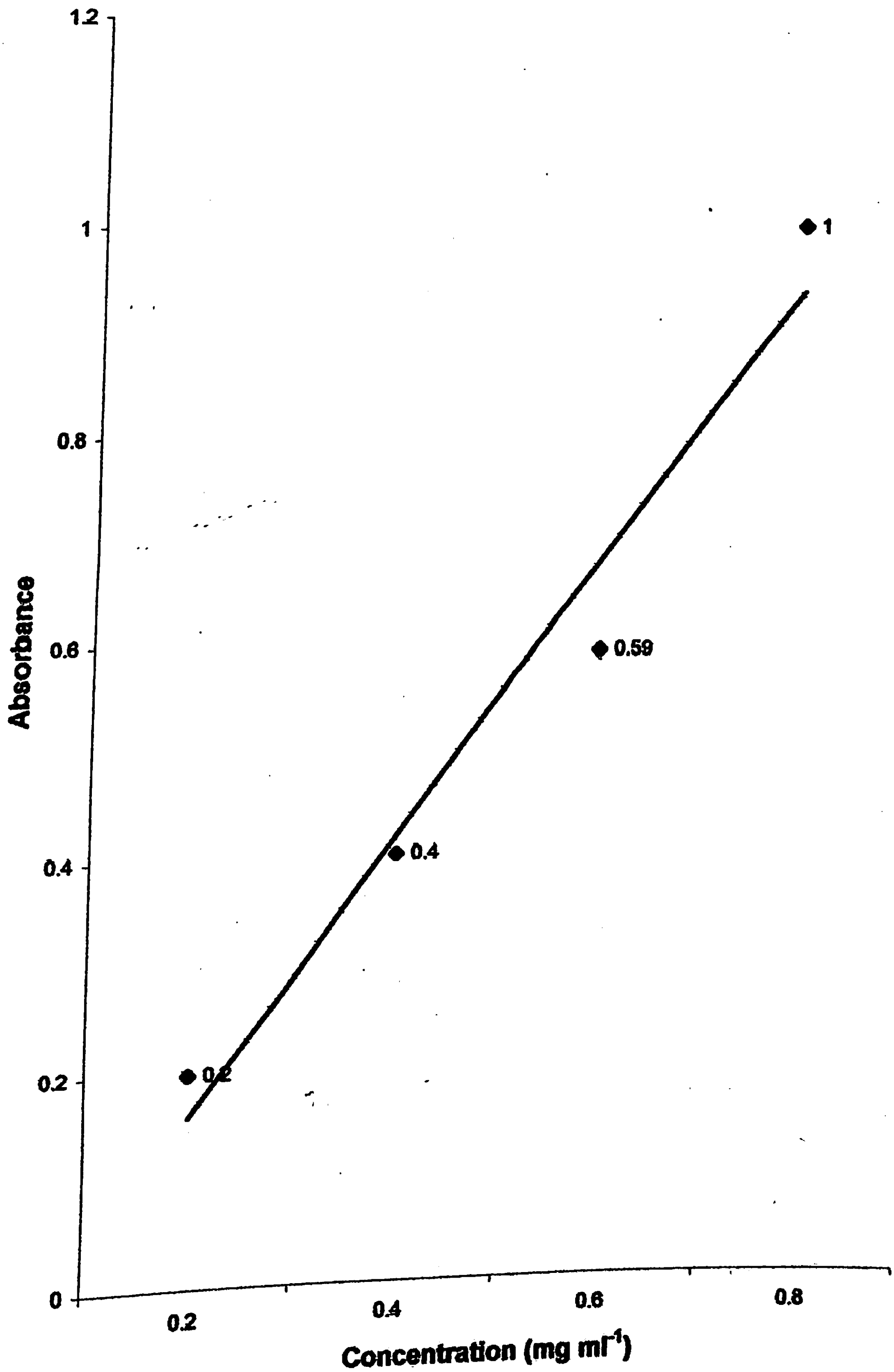
APPENDICES

APPENDIX - I

Standard curve for the determination of total carbohydrate and total soluble sugar



APPENDIX II

a)Physical properties of different oils

Type of oil	Specific gravity	Solidification point	Acid value	Saponification value	Iodine value	Reichert Miessel number
Coconut oil	0.926	14 to 22^{0}C	2.5 to 10	253.4 to 262	6.2 to 10	6.6 to 7.5
Palm oil	0.924 to 0.858^{100}	35 to 42^{0}C	10	200 to 205	49.2 to 58.9	0.9 to 1.9
Sunflower oil	0.924 to 0.927	-10 to –16	0.3 to 1.8	189 to 198.5	129 to 136	0.5

b) Fatty acid composition of different oils

Coconut oil	Sunflower oil	Palm oil
Caprylic acid 7.6 Caplic acid 7.3 Lauric acid 48.2 Myristic acid 16.6 Palmitic aci 8.0 Palmitoleic 1.0 Stearic acid 3.8 Oleic acid 5.0 Linoleic acid 2.5	Palmitic acid 7.0 Stearic acid 3.3 Oleic acid 14.3 Linoleic acid 75.4	Lauric acid 0.1 Myristic acid 1.2 Palmitic acid 46.8 Stearic acid 3.8 Oleic acid 37.6 Arachidic acid 0.2 Eicosenoic acid 0.3

Source:Theodre,J.W.(1998),Food Oils and their U,Ellis Horwood Ltd.

APPENDIX III

Permeability properties of different packaging materials

Film	Permeabilty.(cc/m^2.day.atm.for 100gauge film at 25^0 C			Water vapour Transmission g/m^2.day.atm.at 38^0C and 90% RH
	Oxygen	Carbon dioxide	Nitrogen	
Polyethylene (LD)	7800	42000	2800	18
Polypropylene	3700	10000	NA*	10-12

Source: Athulya, A.S . (1982) Plastic Packaging ,Tata Mc.Graw Hill Company

* Not Available

APPENDIX IV

Composition of different medium for the enumeration of microbes

Nutrient Agar Medium	Yeast Extract Malt Extract Medium	Composition of Rose Bengal Medium
Glucose 5.0g	Yeast extract 3.0g	Dextrose 10.0g
Peptone 5.0g	Malt extract 3.0g	Peptone 5.0g
Nacl 0.5g	Peptone 5.0g	KH_2PO_4 1.0g
Agar 15g	Glucose 5.0g	$Mg SO_4 . 7H_2O$ 0.5g
Distilled water 100ml	Agar 15.0g	Rose Bengal 0.03g Streptomycin 0.03g
P^H 7.0	Distilled Water 100ml	Agar 15g
	P^H 5.6	Distilled Water 100ml
		P^H 6.0

Source:Ranganna,S .(1991) Hand book of Analysis and Quality control for fruit and vegetable products, Tata Mc. Graw Hill Publishing Company

APPENDIX V

Equilibrium Relative Humidities for Saturated Salt Solutions

Salt	Relative Humidity (%)		
	22.8°C	30°C	37.8°C
Ammonium phosphate	92.90	92.00	91.10
Potassium chromate	86.50	86.30	85.60
Ammonium sulphate	80.10	79.60	79.10
Sodium chloride	75.50	75.20	75.10
Sodium acetate	74.80	71.40	67.70
Sodium nitrite	64.80	63.30	61.80
Sodium bromide	58.50	56.30	53.70
Sodium dichromate	54.10	52.00	50.00
Magnesium nitrate	53.50	51.40	49.00
Potassium nitrite	48.60	47.20	45.90
Calcium nitrite	51.80	46.60	38.90
Potassium thiocyanate	46.60	43.70	41.10
Potassium carbonate	43.90	43.50	43.40
Chromium trioxide	39.20	40.00	40.20
Magnesium chloride	32.90	32.40	31.90
Potassium acetate	22.90	22.00	20.40
Lithium chloride	11.10	11.20	11.10

Source: Ranganna, S, (1995). Hand Book of analysis and quality control for fruit and vegetable products (IIed). Tata mc Graw Hill Publishing Company Ltd. New Delhi.

APPENDIX VI

Score sheet for individual judge

Sample No. ----------------
Date of Sampling--------------

DETAILS OF SAMPLE CAN:
a) Product-----------------------
b) Type-------------------------
Date of manufacture------------------

FACTOR SCORE POINTS		SAMPLE CANS								
		1	2	3	4	5	6	7	8	9
COLOR	A									
	B									
	C									
	D									
TEXTURE	A									
	B									
	C									
	D									
TASTE	A									
	B									
	C									
	D									
FLAVOUR	A									
	B									
	C									
	D									
GENERAL ACCEPTABILITY	A									
	B									
	C									
	D									

Signature

APPENDIX VII

Mirobial spoilage of fruits

storage days	Nendran				Robusta				Poovan				Palayankodan			
	Control	Vacuum packed	Refrigerated	Refrigerated cum vacuum packed	Control	Vacuum packed	Refrigerated	Refrigerated cum vacuum packed	Control	Vacuum packed	Refrigerated	Refrigerated cum vacuum packed	Control	Vacuum packed	Refrigerated	Refrigerated cum vacuum packed
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	7.67	3.43	0	0	6.54	3.21	0	0	6.83	3.22	0	0	10.45	3.15	0	0
12	36.18	8.32	0	0	43.15	6.52	0	0	38.54	7.53	0	0	80.56	8.59	0	0
16	100	12.5	0	0	100	15.15	0	0	100	13.54	0	0	100	12.3	0	0

APPENDIX VIII

Oil consumption of chips at different temperature levels for different duration

Temperature levels (°C)	Duration of frying (min)	Vol. of oil consumed(ml)	Weight loss of chips (%)	Temperature levels (°C)	Duration of frying (min)	Vol. of oil consumed (ml)	Weight loss of chips (%)	Temperature levels (°C)	Duration of frying (min)	Vol. of oil consumed (ml)	Weight loss of chips (%)
95-98	10	90	2.5	95-100	10	77.5	20	95-101	10	80	6.67
95-102	15	70	32.17	95-103	15	65.0	33.30	95-106	15	70	33.33
95-108	20	76.65	36.8	95-107	20	63.35	38.33	95-109	20	76.65	43.33
95-112	25	93.3	38.33	95-110	25	66.67	38.33	95-113	25	93.33	37.50
105-108	10	79.15	6.67	105-110	10	75.0	15	105-108	10	79.15	20
105-113	15	76.65	34.58	105-114	15	63.35	35	105-114	15	46.67	38.3
105-115	20	75.0	38.35	105-118	20	65	41.67	105-118	20	72.0	35
105-126	25	76.65	41.67	105-125	25	73.30	48.58	105-129	25	76.65	45
115-128	10	86.85	28.33	115-118	10	75.8	25	115-118	10	75	30
115-140	15	66.65	38.32	115-125	15	66.65	36.18	115-128	15	43.37	41.67
115-168	20	82.3	46.67	125-137	20	84.75	41.67	115-132	20	56.78	41.67
115-173	25	43.3	64.17	115-149	25	94.56	50.0	115-149	25	82.15	53.33
126-130	10	83.3	12.5	125-133	10	62.5	27.5	125.131	10	80.95	36.67
125-143	15	75	39.5	125-135	15	48.5	42.0	125-138	15	43.45	36.67
125-165	20	80	46.67	125-144	20	86.45	50.63	125-143	20	56.78	45.0
125-178	25	96.67	50.83	125-156	25	90.35	56.54	125-163	25	83.45	50.11

APPENDIX IX

Economic analysis for the preparation of nitrogen packed chips

The cost of production of one kilogram of chip is worked out on the basis of following assumptions.

i. The capacity of the small scale unit is 100 kg of raw banana per day of 8 working hours.

ii. The unit will work 1500 hrs in a year

iii. The total annual production of the unit is 9000 kg of chips

iv. Number of 500 gauge polyethylene cover in 1 kg is 80

v. Number of 250 gauge polyethylene cover in 1 kg is 150

vi. Time taken for packing 1 kg of chips in 1 cover is 2 min.

Calculation	Rs.
Cost of constant temperature frying pan	10,000.00
Cost of packaging setup	13,000.00
Total capital	23,000.00
Fixed cost	
Interest on capital cost at the rate of 16%	3,680.00
Depreciation at 10%	2,300.00
Repair and maintenance at 10%	2,300.00
Total fixed cost	8,280.00
Total cost/kg of finished product	$\frac{8280}{9000}$ = Rs.0.92/kg ≈ Rs.1.00

Operation cost

Labour charge/kg of chips (Peeling+slicing+frying)		3.50
Total labour charge		15,000.00
Oil	$\frac{30}{8} \times 1500 \times 36$	2,02,500.00
Raw banana	$\frac{100}{8} \times 1500 \times 12.5$	2,35,000.00
Salt		2,500.00
Cost of packaging materials	$\frac{85}{80} \times 9000 + \frac{85}{100} \times 9000$	14,600.00
Cost of gas	$\frac{450}{7} \times 7 \times 10^{-3} \times 9000$	4,000.00
Operation cost including raw material		4,73,600.00

Operation cost including raw materials per kg of chips $\frac{4,73,600}{9,000} = 52.62$ = Rs.55

Electricity charge

Equipment	Load kW	Number of hours of working	Energy (units)
1. Constant temperature frying pan	4.5	1500	6750
2. Packaging	0.373	300	112

Total energy 6862 unit say 7,000

Total cost 7000 x Rs.2
14,000.00

Total electricity charge per kg of chips $\frac{14,000}{9,000} = 1.50$

Total cost/kg of chips 1 + 55 + 1.5 = Rs.57.5

STORAGE STUDIES ON PRESERVATION OF BANANA AND IT'S PRODUCTS

BY
SINDHU BHASKAR

ABSTRACT OF THE THESIS

submitted in partial fulfillment of the requirement for the degree

MASTER OF TECHNOLOGY IN AGRICULTURAL ENGINEERING

Faculty of Agricultural Engineering & Technology
Kerala Agricultural University

Department of Farm Power, Machinery and Energy

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY,
Tavanur, Malappuram, Kerala

2000

ABSTRACT

The primary objective of this study was to conduct shelf life studies like vacuum packing and nitrogen packing on storage of banana and its products and to suggest optimum storage conditions. The study mainly concentrated on development of equipments for optimising the processing and storage conditions. A constant temperature frying pan was developed for optimising the frying temperature, duration and type of oil. The capacity of the constant temperature frying pan is 100 kg of raw banana per day of 8 h. A low cost set up for nitrogen packing was also developed. Vacuum packing as well as nitrogen packing can be done satisfactorily. Raw banana stored under vacuum cum refrigerated packing showed maximum shelf life up to 20 days without any quality deterioration. The chips fried in coconut oil at a temperature 115 °C for a duration 15 min stored under nitrogen packing showed best results followed by chips fried in coconut oil at a temperature 105 °C for 20 min under nitrogen packing. These results were on the basis of organoleptic evaluation. Jaggery coated chips and banana powder stored under nitrogen packing was the best among four treatments after storage of two months. The economic analysis showed the cost of entire operation for the processing of chips was Rs.57.5 per kg of chips.

The moisture content of raw banana have significant effect on cooking duration therefore the moisture content of banana slices prepared for chips making should be standardised. The peeling and slicing operations are done manually. The speed of the labourers have considerable effect on capacity of constant temperature frying pan.