POSTHARVEST HANDLING AND PACKAGING SYSTEMS FOR BANANA *Musa* (AAB) 'NENDRAN'

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled "**Postharvest handling and packaging systems for banana *Musa* (AAB) 'Nendran'**" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled "**Postharvest handling and packaging systems for banana *Musa* (AAB) 'Nendran'**" is a record of research work done independently by **Mrs. Nallamothu Gouthami**, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship for her.

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CERTIFICATE

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Introduction

INTRODUCTION

Banana, one of the most important tropical fruits of the world, is also known as 'Adam fig' and 'Apple of Paradise' because of its antiquity. It is the most popular fruit in world in terms of percapita consumption. The percapita consumption of banana has increased considerably in the recent years keeping tune with change in consumer's attitude towards healthy eating habits.

Banana is grown all over the world in an area of 3,926.23 thousand hectares with a production of 58,687,214 Metric tonnes. In India, banana is grown in all parts of the country covering about 445 thousand hectares, with an annual production of over 11,000,000 Metric tonnes (F.A.O. 2001). In Kerala it occupies an area of 80.64 thousand hectares with an annual production over 793.33 thousand tonnes. (Farm Guide 2000).

In Kerala, the cultivar 'Nendran' is a pick of varieties. It has high demand because of its multifarious uses. As the other cultivars of banana, 'Nendran' also has short shelf-life. Being one of the high priced varieties of banana in Kerala, attempts to extend the shelf-life by a few days will be a boon to both producers as well as the traders and consumers.

Under commercial conditions mature banana fruits are gathered in the green condition to be artificially ripened through a smoke contact treatment. This treatment helps ripening faster, but the method is crude and it also gives a smoky flavour to fruits, which is not desirable. An easy, fast and safe method of ripening of banana is therefore a felt need in postharvest handling system of banana.

Research efforts have helped to increase production of banana, but the purpose of obtaining maximum profit will not be served unless the increase in production is supplemented with suitable efforts that minimize their postharvest losses. Poor postharvest handling practices and lack of storage facilities result in spoilage of a substantial part of the harvested banana before it reaches the consumers table. There is, therefore, a need to develop simple and inexpensive method for delaying the ripening of banana.

Postharvest deterioration of plantains and bananas is due to important metabolic process like transpiration and respiration, before and after harvest. Refrigeration is a method commonly used to extend the storage life of many commodities by reducing the rate of respiration. However, reducing the temperature during prolonged storage period is limited by susceptibility of banana to chilling injury. In India, bananas are usually handled at ambient temperature. One of the methods of extending shelf-life is the use of ethylene scavengers. Placement of an ethylene absorbent in the modified atmosphere of a polyethylene bag has been found to increase the storage life of fruits.

In Kerala, as the fruits are sold on weight basis, loss of water from the produce can be construed as direct loss of salable weight. To reduce the transpiration loss, bananas can be packed in polyethylene bags, where the composition of the storage atmosphere helps to keep the fruit fresh for a longer period of time. Further gain, in storage life can be obtained by coupling refrigeration with modified/controlled atmospheric storage.

With the fast changing retail-marketing system with super markets in the center point, the produce for retail marketing necessitates more thrust on quality and appeal of the produce. Suggesting guidelines for grading bananas would help farmers get a premium price for the best produce.

Hence the present study was taken up with the following specific objectives.

1. To study the postharvest behaviour of banana (Var 'Nendran').
2. To standardize techniques for extending postharvest life of banana (C.V. 'Nendran')
3. To develop packaging systems for retail handling of banana (C.V. 'Nendran')
4. To make an attempt for developing a grading system for banana (C.V. 'Nendran') fruits.

Review of Literature

REVIEW OF LITERATURE

Postharvest research is concerned with maintaining crop quality until the harvested produce reaches the consumer. This research is important especially for perishable crops like banana. Lot of research is going on round the world and new techniques have been developed to improve the shelf-life and also to maintain quality of bananas. Development around the world in postharvest handling, grading, packaging and storage of bananas and few other crops has been reviewed in the following pages.

2.1. Harvest Maturity

A fruit is said to be mature and ready for harvest when it is at the end of physiological development. The time required for maturation differs with the variety and climate. The degree of maturity at harvest is of prime importance, which depends on the type of market weather the fruit is meant for local market or for distant market. For local or retail marketing, 90-100% mature bunches are harvested and they ripen in less than a week. (Pentastico, 1975).

2.1.1. Maturity Indices

2.1.1.1. Degree days

Maturity can be predicted from temperature data, since rate of fruit maturation from shooting depends on temperature where moisture is not a limiting factor. The use of degree days is not significantly accurate by itself in predicting harvest dates for commercial purposes.

2.1.1.2. Shoot to harvest records

The number of days from flower emergence to maturity is based on the physiological age. When bunch is harvested by grade alone without knowing the age (time from bagging to harvest), a mixture of fruit differing in age by as much as 50 days can be present in the same box thus leading to risk of 'ripes' in transport. For an age-grade control programme, it is necessary to have some data on days from shooting or bagging to harvest throughout the year. For this tagging is done using various coloured ribbons on the pedicel. After the required number of days from bagging, all bunches with ribbons pertaining to the designated weeks colour is harvested (Stover and Simmonds, 1987).

2.1.1.3. Angularity of Fingers

Fruits are graded as three quarter (fruits with clearly visible angles, about half of their maximum size), full three-quarter (fruits with less prominent angles) or full stages (fruit angles have virtually disappeared). However, one should not rely solely on the disappearance of angularity as the basis of maturity since there is little agreement between the terminologies used a phase such as 'light full three-quarter' cannot be assumed to have the same meaning in different places and the term 'fullness of fingers' is not applicable for cooking cultivars that remain angular even at full maturity (Anon, 1988).

2.1.1.4. Caliper-grade

For the export market, maturity requirement depend on the specifications provided by the importing countries, calibration size and length of finger are the most commonly used indices. For determining caliper grade, the middle finger in the outer whorl of the second hand is callipered at the thickest part of the fruit. The grade is expressed in three ways depending on the country total thirty-seconds of an inch, the number of thirty-second of an inch above thirty-two or in millimeters. The former is used in central and South America, while millimeters are used in Caribbean and Africa. Fruits with calibration of 40/32 to 48/32 are considered mature for harvest (Anon, 1988).

Montoya *et al.* (1984) worked out the correlation between potential green-life and either caliper grade at harvest or age at harvest and found higher correlation coefficients with age than with caliper grade with potential green-life of hand varying between 18 and 53 days. N'Da-Adopo *et al.* (1996) reported that yield, quality and marketing value of the product were higher with longer periods between flowering and harvest.

2.2. Ripening

Ripening of fruit may be defined as the sequence of changes in colour, flavour, sweetness, and texture. Banana fruit are not allowed to ripen on the tree as it takes longtime even if ripened, the peel split rendering the fruit easy prey to insects and diseases. Therefore, under commercial conditions mature bananas are gathered green to be artificially ripened. For artificial ripening of banana treatments like smoking, or treating with other chemicals like ethylene, acetylene and coal gas are used commonly (El-Banna, 1976).

2.2.1. Use of Ripening Agents

The primitive method is the use of smoke as a ripening agent. On a commercial scale still smoking is carried out for two or three days or even longer. Smoked fruits have black specks and other skin blemishes besides producing a smoky flavour, which makes it difficult to market (Shenmugavelu, *et al.*, 1992).

Agnihothri and Ram (1971) stated that smoke treatment showed the maximum rate of respiration there by showing that smoke treatment did enhance the process of ripening and the smoked fruit had poor shelf-life, eating quality, texture and flavour.

A more feasible and commercially viable method for ripening bananas on a large scale was investigated and ethephon, ethylene releasing chemical was found to be more effective.

Rao *et al.* (1971) reported ripening of bananas in 48 hours with the use of ethylene evolved from ethrel solution of 5000ppm and with addition of sodium hydroxide pellets. Green-life of bananas reduced by exposing the fruits for short periods to ethylene (Peacock, 1972) the length of exposure and ethylene concentration being such that ripening is not immediately initiated but begins several days or even weeks after treatment.

Investigations on the effect of ethephon on ripening of banana by El-Banna (1976) showed that bananas treated with high levels (500 and 1000ppm) have reached maximum ripening condition in four days and the fruits treated with low levels (100 and 250ppm) had longer fruit marketable period. Variance due to time of dipping was not noticed and ethephon was found to be an easy, fast and safe chemical for artificial ripening of banana fruits.

Enhanced ripening, of fruits of banana C.V.Williams treated directly with 1000ppm ethephon was reported by Shaaban (1988). Similar effect, was reported by Gosh *et al.* (1997). They also reported that 500ppm ethylene was equally effective in inducing ripening, though the rate of ripening was slower and the fruits sprayed with 500ppm ethylene, when stored under conditions with adequate oxygen availability registered better colour development and the required softness. Fruits ripened fast (i.e.) five to six days to reach the edible ripe stage when placed in a air tight cabinet containing a beaker of 250ppm ethrel and 2% NaOH for 24 hours and then kept in ambient conditions. Fruits dipped in 250ppm ethrel took 7.8 days to reach the same state (Gobardhan, 1994).

2.2.2. Physiology of ripening

Banana is a climacteric fruit (i.e.) the ripening process is associated with a burst of respiration, which reaches a peak after three or four days and then declines but remains high. A few hours before the respiratory climacteric begins there is a peak increase in ethylene evolution and this peak in ethylene evolution occurs when the respiration rate is increasing rapidly. As fruit ages in the pre climacteric phase lower concentration of exogenous ethylene will stimulate ripening. This may be due to the increasing sensitivity of the fruit tissue to ethylene or dissipation of an inhibitor or an accumulation of endogenous ethylene (Turner, 1997). In pre climacteric phase small amounts of ethylene is generated and there is insufficient ACC oxidase, this is referred to as system 1 ethylene production and exogenous ethylene stimulates endogenous ethylene production by increasing ACC oxidase resulting in an ethylene climacteric this auto catalytic biosynthesis of ethylene is system 2. The 'system 2' ethylene biosynthesis is exploited in artificial ripening of bananas.

Littmann (1972) reported that a decrease of 50% or more in fresh weight reduced the green-life or time elapsing until the onset of the climacteric and a 20 percent decrease in fresh weight induced abnormal ripening with decreased pulp softening and excessive skin browning. Pre climacteric ethylene production was stimulated by water stress. However, chlorophyll degradation was not noticed.

Peacock (1980) found that banana C.V. Giant Cavendish stored at 26.7°c and above showed poor skin colour and an exponential decrease in shelf-life with increasing temperature. Weight loss was found independent of temperature, provided, relative humidity was kept high (> 95%).

The phenomena associated with ripening of banana fruit include changes in colour which include loss of chlorophyll leading to the unmasking of underlying pigments and synthesis of new pigments accompanied by alterations in flavour, astringency, sweetness, sugars, volatiles and texture. The postharvest changes are observed in banana fruit before it reaches the edible ripe stage apart from its physiological activities such as respiration and transpiration etc. (Waskar and Roy, 1993).

In an experiment to study the effects of elevated temperature and lower ethylene concentration on the ripening of banana C.V. Giant Cavendish by Ke and Ke (1980) found that regardless of their maturity when harvested, fruits treated with any of the five concentrations of ethylene (10, 50, 100, 500 or 1000ppm) ripened at 22°C or 24°C and high temperature or low ethylene treatment may therefore be used to ripen fruit harvested early.

Hughes and Wainwright (1994) while studying the influence of site and fruit position on the pulp colour and texture of banana found no significant variation in texture and only a small difference in colour in fruits from different position within the bunch. The pulp colour coordinates texture and green-life of fruit of standard commercial harvest maturity obtained differed significantly between production sites. A study by Marin *et al.*(1996) revealed that of the green and ripe 'Grand Naine' bananas harvested 13 weeks after flowering in June, September, February and March had identical ethylene production and ripening rate which indicates a small influence of the season on physiology also the position of the fruit in the bunch had no effect.

Acuna (1997) reported variation in the duration of pre climacteric period among different harvest criteria (age and grade) but found no significant variability in the position of the hand in the bunch.

Bin *et al.* (1995) found that low relative humidity hastened the yellowing of the peel and advanced the onset of the respiratory climacteric and ethylene production by about 6 and 12 days at 65% and 95% R.H. respectively at 20°C and concluded that the R.H. in the storage atmosphere affected weight loss of banana fruits and ultimately the ripening characteristics. Fruits held in the higher R.H. combination particularly high R.H. after ethylene gassing had greener peels and firm fruit with less peel scarring and high relative humidity caused less compression injury (Blankenship and Herdeman, 1995).

2.2.3. Chemical Changes During Ripening

Ripening changes studies in three plantation cultivars by Marriott *et al.* (1981) have shown that plantains contain about 9per cent starch when fully ripe and the total sugar content increase from 20per cent at full-ripeness to 27per cent when overripe and the ratio of glucose to fructose was found to be approximately unity for banana and plantains at all stages of ripeness. A progressive loss in firmness, rise in acidity and increase in sugar in pulp with the advancement of ripening of bananas was reported by Sen *et al.* (1982). Kojima *et al.* (1994) have stated that the decrease in the viscosity and elasticity of pulp, the major physical factors associated with pulp softening is related to the sequential degradation of starch, pectin and hemi cellulosic polysaccharides in pulp cell walls. Investigations by Ngalani *et al.* (1999) on starch and sugar changes in the fruits of two plantain cultivars in ambient condition at three stages of ripeness showed a decrease in pulp firmness and the starch content of the pulp, from stage one to five a significant increase in the reducing sugar content and °Brix of pulp. Sivashankar (1999) reported that accessions of AAB registered very low PLW values ranging from 1.81-4.8% and titrable acidity ranging from 0.5-1.05 and a higher shelf-life of 9-10 days.

2.3. Precooling

To achieve maximum storage for a crop or to reduce losses during its marketable life it is essential to keep it at the most appropriate temperature, this is usually just above that which will cause chilling or freezing injury. To maximize the effect the crop would be brought to that temperature as quickly as possible after harvest. This is known as crop precooling (Thompson, 1996).

Rodriguez *et al.* (1995) reported that precooling (hydrocooling) for five and ten minutes combined with storage at 21°c for the first 24 hours or storage at 13°c straight away maintained the green colour of the fruit for 20±2 days. Fresh weight loss was not affected by treatment. Precooling duration more than ten minutes are not recommended due to the lowering of pulp temperature close to 13°C, pre disposing the fruit to chilling injury.

Ethylene levels within polyethylene bags packed with bananas with transit cooling were lower than in polyethylene bags without transit cooling during storage (Arec *et al.*, 1996). Kapse and Katrodia (1997) while studying on hydrocooling in Kesar mango found that longest shelf-life (14.3 days) occurred in fruits precooled at 12°c, followed by those precooled at 16°C (12.3 days) and the controls (10.2 days).

Nayak and Thangaraj (2000) studied the effect of different precooling methods viz, hydrocooling, contact-icing and air cooling in delaying ripening of bananas harvested at 80% maturity and found that hydrocooling at 5°C for 60 minutes extended shelf-life up to 15 days compared to 12 days in non-precooled fruits. Hydrocooled (45-60 minutes) fruits reached final ripening stage after 16-17 days compared to 15th day in control. The quality of hydrocooled fruits remained unaffected, while the PLW was reduced to 11.68% when precooled for 60 minutes compared to 15.39% in control.

2.4. Chilling injury

Chilling injury is where crops develop temperature associated physiological disorders or abnormalities when exposed to temperature above those which would cause them to freeze. Chilling injury may be apparent as failure to ripen in climacteric fruit and different forms of external or internal discoloration or pre disposition to microorganism infection (Thompson, 1971).

Chilling injury in banana fruit reduced with lowering the storage temperature and with extending the duration of exposure of lower temperature. Chilling injury symptoms become more clear upon removal of fruits to room temperature and the banana fruits failed to ripen when held at 0° or 5°c for 20 days (Aziz *et al.*, 1976). Studies by Jones *et al.* (1978) have revealed that under peel discoloration of banana can be prevented by postharvest treatment with dimethyl polysiloxane, sunflower oil and mineral oil for 48 hour treatment at 9°C, and this increased shelf-life and decreased water loss.

Mattei (1978) suggested that cooling the fruit slowly could reduce chilling injury in bananas, reducing the oxygen level of the atmosphere to 2 – 3 % and maintaining high relative humidity and storage temperature of 12°C caused less fruit injury than 4°C. Satyan *et al.* (1992) worked on the comparison storage behaviour of cooking bananas in air and in modified atmosphere at 28, 20, 13, 7 and 3°C and showed that all the cultivars responded markedly and the storage life was increased by a factor of two in the absence of an ethylene absorbent and a factor of three when absorbent was present. Reducing the storage temperature from 28° to 13°C further increased the shelf-life. Cultivars differed in their susceptibility to chilling injury and the use of M.A. with and without ethylene absorption had no effect on the incidence of chilling injury.

2.5. Hot water treatment

Harvested produce could be immersed in hot water before storage or marketing to control diseases. A common disease of fruits, which could be successfully controlled in this way, is anthracnose, caused by infections of the fungus *colletotrichum* spp. Postharvest treatment with fungicide is generally reported to be ineffective in controlling the disease but immersing them in hot water preferably containing an appropriate fungicide can give good disease control (Thompson, 1996).

Amstrong (1982) had developed a 15 min, 50°C hot water immersion treatment as an alternative quarantine treatment to ethylene dibromide fumigation for 'Brazilian' variety bananas against the Mediterranean fruit fly, the melon fly and the Oriental fruit fly. The hot water immersion disinfected 'Brazilian' variety bananas without detriment to either fruit quality or shelf-life.

Banana fruits harvested mature green and immersed in water at 50°, 52° or 54°C for 10, 15 or 20 minutes and treated with ethylene in the ripening room for one to three days after treatment and held at 15-20°C for up to 14 days. The 50°C/15 minutes and 54°C/10 minutes treatment gave the greatest reduction in ripening without affecting fruit quality (Frith and Chalker, 1983). Lurie (1998) reported that when a heat treatment was administered to tomato fruits their sensitivity to low temperature was reduced and they could be stored for up to a month at 2°C without developing chilling injury. Dominquez *et al.* (1998) studied on the effect of hot water dips (HWD) on the ripening, ethylene metabolism and commercial quality of "Santa Catarina Prata" (AAB) and Dwarf Cavendish" (AAA) showed that temperatures below 50°C caused a delay in peel colour development, no effect was found on soluble solids accumulation and increased sensitivity of the fruits.

Lopez-Cabrera *et al.* (1998) reported that the hot water dip with temperatures of 45-47.5°C and immersion times of 15-30 minutes provide an excellent way of controlling the growth of fungi on banana axis disks. Low temperature and shorter times also showed a positive effect. Temperatures more than 50°C caused peel darkening and incomplete soluble solids accumulation. They opined that the effect of HWD on growth may be due to an inhibition of spore germinator or may be due to induction of banana antifungal compounds.

Yong hong *et al* (1998) found that the treatment of 45°C hot air for 12 minutes inhibited the degradation of peel chlorophyll-a, compared to control. Peaks of respiration rate and ethylene evolution occurred later than the control. and also found that the treatment of banana with water at 55°C for 10 minutes or longer caused severe skin scald and resulted in a failure to ripen and it was reported that the hot water treatment has the potential to replace chemical fungicide to control crown rot of banana.

2.6. Storage

Bananas and plantains have a relatively short postharvest life of a few days or weeks even under good conditions. The term storage may be interpreted as 'putting away for further use' to the use of an environmental factor to extend green-life, to manage the rate of ripening or to extend shelf-life. Storing is about managing green-life, the initiation of ripening and subsequent shelf-life. According to Peacock and Blake (1970) green-life is the time a harvested fruit takes to reach maturity under defined conditions (i.e.) in a humified air stream at 20°C in the absence of exogenous ethylene and below the critical green-life represents the auto catalytic ethylene synthesis.

Dalal *et al.* (1969) reported that when three fourth full matured Dwarf Cavendish bananas were loaded into refrigerated shiploads within 60 hours after harvesting and cooled down to 60°F within 12 hours gave a better quality product and the percent of acceptance was high 94% and above. Bananas stored at 48°F and 54°F developed chilling injury in 7 and 23 days respectively. Bananas cold stored for 21 days at 69-70°F and when ripened within 10 days by smoking were acceptable in colour, taste and flavour. Whole bunches of Dwarf Cavendish bananas could be successfully stored for 25 days when stored at 14.4°C and 80-90% R.H. When compared within 7 days at room temperature (Muthuswamy *et al.*, (1971). In an experiment by Blake and Peacock (1971) on the effect of temperature on the pre climacteric life of bananas it was found that over the range of 60-96°F, the green-life of C.V. Monsmari was logarithmically related to temperature.

Titrable acidity and respiration rate remained lower in fruits stored at 5°C than those held in room temperature. Low temperature might influence the oxidation of Dopamine (Phenolic constituent of banana peel) to dark coloured substances (Gemma et al., 1994).

Rippon and Trochoulias (1976) found that the shelf-life is affected not only by temperature during the prior period of ripening. In C.V.Williams, shelf-life of fruits ripened at 16°C was ten days if, after five days of ripening, the fruits were removed to 21°C, ripening the fruit at 19°C and adopting the same removal time and temperature, reduced shelf-life to two days.

Green unripe 'Robusta' bananas at two stages of maturity could be held at 15° and 20°C for one to four weeks, followed by proper ripening at ambient condition. Fruits remained green, firm and unripe for two to three weeks at these temperatures. Weight loss was found to be less in fruits held at 15°C and 20°C. Quality of fruit after one to four weeks of holding at 20°C was the best followed by fruits held for three weeks at 15°C. By harvesting the fruits early at 100 days after fruit set, shelf-life could be extended from 16-21 days at ambient storage (Krishnamurthy, 1989).

Ramana *et al.* (1989) studied the postharvest storage of banana and guava at ambient temperature (9-30°C) and showed that by continuously flushing the storage atmosphere with air saturated with moisture it is possible to ensure less weight loss and showed changes in firmness and brix:acid ratio and as a consequence extended the storage life by five days as compared to the control.

Singh and Prasad (1993) reported little disease development at 20°C and maximum deterioration of fruit pulp in the two varieties at 30°C and fruit spoilage in storage with maximum disease at 96% R.H. Wasker and Roy (1993) in a study on the effect of zero energy cool chamber on storage of banana found that fruits stored in cool chamber ripened either by commercial method or by ethrel is beneficial for extending the shelf-life up to 20.5 days as compared to 14 days of room temperature, the advantage of storage in a zero energy cool chamber over a cool storage was that it did not require any mechanical or electrical energy and was easily installable with inexpensive and locally available materials such as bricks, river sand, bamboo and khas. Zhang *et al.* (1993) opined that high temperature in storage accelerates softening of the pulp and inhibit chlorophyll break down in the peel thus leading to the "green ripe" condition.

Rahman *et al.* (1995) reported that the yellowness of the fruits of Apple banana (Musa AA) was not affected by temperature over the range 14 - 25°C, but the fruits ripened at 14 -18°C retained more peel green colour when fully ripe than those at the higher temperature. Fruits ripened at low temperature were firmer in texture and 20°C was found to be the ideal ripening temperature with regard to the flavour.

Ram and Vir (1996) found an increase in activity of the fungi as the storage temperature rose to 25°C resulting in greater percentage infection. A further increase in storage temperature to 30°C, resulted in reduced infection with increasing R.H. levels and that all the test fungi caused complete decay of banana fruit at 100% R.H. Green, ungassed bananas when placed under C.A, the presence of ethylene in the atmosphere did not cause the bananas to turn yellow although some changes in P^H and soluble solids were detectable. Bananas that have ripened under CA condition are not as high quality as those ripened in air in terms of visual appearance (Blankenship, 1996).

Agho *et al.* (1996) developed a new storage technique of plantain, bananas with local plant material like powdered cocoa leaves, pods, powdered coffee and rice husks, which extended, the life of green plantain to more than two weeks at 30°C and to more than four weeks at 20°C without loss. Powdered cocoa leaves and especially rice husk are the best plant substances for extending the life of green plantain.

2.6.1. Controlled and Modified Atmospheric Storage

Controlled atmospheric storage (CAS) implies addition or removal of gases resulting in an atmospheric composition substantially different from that of normal air. Thus CO_2, O_2, C_2H_4 or N_2 can be manipulated to attain various gas combinations. Commonly CAS is the term used for high CO_2, decreased O_2 and high N_2 levels as compared with normal atmosphere (Do and Salunkhe, 1975). An increase in shelf-life of bananas stored in CA has been reported by many workers (Eksteen and Truter, 1989; Krishna Murthy *et al.*, 2000, Shukor *et al.*, 1997).

Modified Atmospheric Storage (MAS) also requires decrease in O_2 and increase in CO_2 and N_2 but there is no attempt to control the atmosphere at specific concentrations. (Do and Salunke, 1975).

Chiang (1970) reported that mature green bananas stored at 20°C in N_2 with or without CO_2 (8-15%) for a week, ripened as quickly in air as the control kept continuously in air. N_2 plus CO_2 had a more damaging effect on the cytoplasmic resistance to stalk rot than N_2 alone. Bananas stored in 1% O_2 for 2 months showed more stalk rot than those stored in 2% O_2 though low O_2 and high CO_2 lowered the ripening rates. Exposure of pre climacteric banana C.V. Cavendish and Williams to less than one percent oxygen for approximately three days followed by storage in air extended the time required for the fruit to ripen (Wills *et al.*, 1982).

The storage life of bananas was also extended when fruits were held in a modified atmosphere containing 10% CO_2 for 1 or 3 days followed by storage under regular atmospheric conditions at 12.5°C (Truter and Comb rink, 1990).

Valdez and Mendoza (1988) recommended that banana fruits C.V. Bungulan should be held at 25°C for one day prior to MAS for minimizing spotting of bananas induced to ripen with ethephon. Nair and Tung (1992) studied behaviour of mature green Mas bananas hermatically sealed in light polyethylene bags where low O_2 cum high CO_2 condition exists and found that the fruits loose very little weight, produce negligible ethylene and ripen normally in air after storage, further they stated that a low oxygen atmosphere is a pre requisite for extended storage and full expression of the organoleptic qualities of the fruit.

Kubo *et al.* (1993) stated that elevated co_2 concentration had no effect on the initiation of banana ripening induced by exogenous ethylene but do reduce the rate of ripening. Wade *et al.* (1993) found that banana (Musa AAA) bunch section of main stalk and could be inoculated with cultures of fungi isolated from diseased fingers and stored in sealed polyethylene bags containing 3-7 $Y.O_2$, 10-13, 10_2 and less than 0.1 $\mu l\ l^{-1}$ ethylene for 40 days at 20°C and then ripened with ethylene in air for nine days caused high infection incidence of *Colletotrichum musae*, *Fusarium monoliforme* var. Sub glutinans and *Nattrassia mangiferae* in unripe fingers during storage.

2.7. Packaging

The function of a package is primarily to contain and protect the produce. Fruit and vegetables being living organisms, give out heat and gases which can be detrimental if allowed to accumulate in the package, so it may need to be ventilated. Certain types of packaging can be used to extend the storage life of crops such as plastic film to modify the atmosphere or to protect the crop from infection or infestation.

The standard containers used world wide for banana is the carton holding the fruits. The box containing of the box top, bottom, a wall reinforcing liner and a divider for separating the rows of clusters polyethylene lined banana are placed in the carton, the plastic liner used may be plain plastic sheet, a plastic bag, perforated or non perforated or a modified atmosphere bag 'Banavac' (Stover and Simmonds, 1987).

Charles and New (1996) proposed solutions to the high cost of packaging by the use of rigid containers for multiple tips, and the introduction of glued trays and pre packing of clusters or individual fruits.

2.7.1. Modified Atmospheric Package (MAP)

MAP is considered as a dynamic system, where respiration of product and gas permeation of film continues to take place simultaneously (Floros, 1990). MAP has proven to be a quite flexible means of extending the shelf-life of fresh fruits. MAP consists of enclosing the fruits in a plastic bag such that there is limited exchange of air, leading to reduction in oxygen levels within three to four days of sealing fruits in polyethylene bags a stabilized modified atmosphere is developed (Gorris and Peppelenbos, 1992).

Sealing fruits in a polyethylene bag is a simple and cheaper method. Plantains sealed in polyethylene bags remain green for a longer period than fruits stored in perforated polyethylene bags, paper bags, or wet coir. As the fruits respire, the atmosphere within the bag decreases in oxygen and increases in carbon dioxide. Respiration is then inhibited because of the reduced oxygen.(Ferris, 1997).

Fuchs and Gorodeiski (1971) reported green unripe banana 'Dwarf Cavendish' fruits stored in sealed polyethylene bags with and without $KMnO_4$, when some fruits were triggered to ripen by ethylene before or after sealing the bags, the presence of ethylene stimulated 'Pectin Methyl Esterase (PME) activity and starch hydrolysis and caused softening, but colour change was inhibited by high concentration of CO_2.

Scott *et al.* (1971) reported that bananas packed in sealed polyethylene bags and transported to distant markets without refrigeration remained hard green even after periods of 8 to 18 days. The polyethylene bags also reduced weight loss and mechanical injury. Best results were obtained by treatment with thiabendazole to control crown rot and by packing an ethylene absorbent with the fruit. Daun *et al.* (1973) have developed a retail package in which ethylene treated bananas were maintained with excellent colour, odour, taste and texture after 30 days of storage at 15 °C. The beneficial conditions were obtained by the use of a film with proper gas permeability for the particular weight of the fruit and package dimensions. The desired O_2, CO_2 and water vapour concentration were generated by the system itself as a result of balance between the respiration of the bananas and the diffusion from surrounding atmosphere through the film.

De *et al.* (1988) reported that wrapping delayed ripening by four to six days in ambient conditions, and by eight days at high R.H. Loss in fruit weight and pulp: peel ratio were less at the high R.H. Respiration was slower in wrapped than in unwrapped fruits irrespective of R.H. Wei . and Thompson (1993) studied the effect of modified atmosphere packaging for extending shelf-life, to allow transporting by sea and have shown that Apple banana packed with polyethylene film and storing at 14°C gave a shelf-life of 21-28 days. But if the film was insufficiently permeable (200 guage) increased CO_2 concentration produced toxic injuries after three weeks. Rahman *et al.* (1995) found that Apple banana packed in 100 guage polyethylene film at 13-14°C, proved that the film was sufficiently permeable to prevent CO_2 level from becoming toxic to the fruits.

Aradhya *et al.* (1995) reported a shelf-life of 50 days for Rasthali bananas by modified atmospheric packaging with ethylene absorbent at optimum low temperatures along with various postharvest treatments and package of practices.

Chillet *et al.* (1995) while investigating the effect of different packaging methods on the development of canker during the storage have found that fruits when placed in large (18 Kg) or small (1Kg) cartons either in closed polyethylene bags or in open plastic film and stored at 13.5°C for 18 days and then placed at 21°C closed polyethylene bags or in open plastic film and stored at 13.5°C for 13 days and then placed at 21°C closed polyethylene bags limited the development of canker compared with classical packaging method using plastic film. Chillet *et al.* (1996) found that during a 28 day storage period at 13.5°C, rates of fungal rot development and fruit ripening were considerably slowed down when polybags were kept sealed, the polybag effect during a longer storage period was due to a modification of O_2 and CO_2 levels in bags and not to reduce fruit weight loss.

Elazayat (1996) found that fruits pretreated by dipping in Thiabendazole @ 400ppm and packed by wrapping in polyethylene before packing in cartons and stored at 13°C or 15°C for one month had a shelf-life of 5-7 days in ambient condition after storage and the fruits ripened normally. Prasad and Singh (1996) have stated that MA packed fruits when stored 10-12°C higher than the refrigerated stores retains the orchard freshness. The gas transmission characteristics of the packaging film laminates can be brought as close to the gas transmission requirement of MAP by tailoring.

2.7.2. Vacuum Packing

Vacuum packing may be regarded as a special type of modified atmosphere packaging, since part of the normal headspace is withdrawn, leaving an altered initial atmosphere (Burg & Burg, 1966).

Studies by Rajeev and SreeNarayanan (1998) on vacuum packing of 'Rasthali' banana in polyethylene bags of different thickness, stored for 40 days in room temperature (28 to 32°C) revealed that by keeping green and unripe banana in evacuated polyethylene bags at room temperature the shelf-life could be maintained more than 40 days compared to other treatments. Further the banana packed in polyethylene bags of 110 micron gave better results than others.

Emerald and SreeNarayanan (1999) while working on prolonging shelf-life of banana fruits CV. Rasthali found that fruits packed under vacuum with and without ethylene absorbent retained freshness, firmness and greenness for 30 days at ambient condition (20-30°C, 66-93% R.H.) when compared to fruits kept in open atmosphere (5 days). The fruits stored under vacuum ripened within three to four days when removed from the bags and kept in open atmosphere.

Geetha *et al.* (2000) reported that raw banana fruits pretreated with waxing, oil film coating, purafil packets, tissue paper wrapping along with control and poly bag packing were stored under vacuum and stored at room (36°C) and refrigeration temperature (20°C). During storage the banana hold shelf-life of four and eight weeks at room and refrigeration temperatures. Increase in shelf-life by packing under vacuum, was reported in papaya, sapota (Geetha *et al.*, 2000) and in Guava by Kannan and Thirumaran (2000).

2.8. Use of coatings

Fruits are dipped or sprayed postharvest with a range of materials to improve their appearance or delay deterioration. The application of fungicidal wax emulsion was beneficial in minimizing the loss in weight, spoilage percentage and delayed the ripening process (Agnihotri and Ram, 1971).

The effects of plastic skin coating on Dwarf Cavendish bananas were investigated by Ben-Yehoshua (1966) and the results showed an extension of storage life by five to fifteen days, and a delay in climacteric rise and the ripening process by one or two weeks as measured by respiratory activity, rate of softening and degreening. Reduction of weight loss by 25 to 50% and incidence of decay of cut surface of fruit and inhibition of the darkening of the banana skin, improvement in glossiness and these fruits showed normal ripening. On ethylene treatment, the internal O_2 concentration was low, a slightly high CO_2 concentration, might have brought delay in ripening.

Dalal *et al.* (1969) reported that banana hands dipped in 1% aqueous solution of Brassicol 75 having an application of CFTRI antifungal paste remained green, clean and fresh and showed no stem end rot for a period of 18 days. Application of CFTRI antifungal parts alone was sufficient to prevent rot. Dalal *et al.* (1970) found that bananas harvested 115-123 days from time of emergence of inflorescence and treated with 8% wax emulsion remained green during 21 days of storage at 55±1°F, RH 85%. Muthuswamy *et al.* (1971) reported that application of paraffin wax seal to cut stem surface slightly reduced the weight loss.

Bharadwaj *et al.* (1984) reported that inclusion of ^{14}C labeled sucrose esters of fatty acids in fruit coating, retarded ripening and opined that the concentration of sucrose esters in the retardation of ripening is unlikely to be dependent upon the migration into the pulp tissue.

Olorunda and Aworh (1984) while studying the effect of Talprolong, a commercial fruit coating on the shelf-life and quality attributes of plantain found that plantains dipped in 1.5% or 2.5% Prolong solution and stored at 30°C showed delayed yellow colour development by four to eight days.

Krishnaiah *et al.* (1985) reported that WT-23 a Decco commercial food grade fruit coating @ 0.01%(CC) 100g fruits was most effective in controlling *Gloeosporium*, the main spoilage fungus. Krishnamurthy and Kushalappa (1985) found no difference in ripening between untreated and Waxol-12% (6%) treated fruits but 1% and 2% Talprolong delayed ripening by four to five days. Waxol-12% was ineffective to extend shelf-life of bananas except when used on packaged fruit.

Hussein *et al.* (1985) reported that 15% Prolong coating was effective in delaying ripening in both Hindi and Paradi cultivars. Banks –NHAD (1985) found that Prolong coating at different times relative to initiation of ripening showed that a climacteric rise in respiration was absent from fruits coated with Prolong immediately before or after ripening initiation, delaying coating by a further 24 hours arrested development of climacteric in mid rise.

Talprolong treated fruits had significantly lower values of T.S.S, reducing sugar, non reducing sugar and titrable acidity and higher values of alcohol insoluble substances and starch, indicating that ripening process in these banana fruits was retarded significantly Desai *et al.* (1989).

Shaikh *et al.* (1991) investigated the suitability of a wax emulsion developed at PCSIR laboratories complex, Lahore, to extend shelf-life of banana and found that coating bananas with the emulsion reduced gaseous exchange between the fruit and the outside atmosphere, thus modifying the atmosphere within the fruit without impeding the ripening process. Al-Zaemey *et al.*(1993) reported that formulation based on Semperfresh acid-stable alone or with potassium sorbate, or sodium benzoate significantly delayed lesion expansion for up to 7 days, but after 11 days incubation difference between treatments and the untreated control were less marked. Sarkar *et al.* (1995) found that the fruits of banana (Musa, AAA group) C.V. Gaint Governor could be kept for 14 days after harvest without affecting the quality if treatment is done with GA 0.02%, Blitox 0.3%, Bavistin 0.1%, Dithane M-45. 0.2% or Waxol-12% or 6%.

2.9. Chemical ripening retardants

Use of ethylene scrubber, which scrubs ethylene from the atmosphere by trapping and / or converting to other products, has been largely studied. Commercial scrubbers made of $KMnO_4$ are most effective. Other treatments that reduce sensitivity of fruit to System 2 ethylene production or inhibit System 2 ethylene production or direct inhibition of a 'key enzyme' early in ripening by chemicals.

Scott and Gandanegara (1974) reported that the storage life of bananas over a range of temperature from 10 to 37 °C was increased considerably by packing the fruit in sealed polyethylene bags and addition of $KMnO_4$ as an ethylene absorbent further increased the storage life. Rao and Chundawat (1986) reported that the rate of ripening was slow in terms of relatively lower percentage of ripe fruits in the fruits, which received Waxol-12% GA (150ppm), Kinetin (10ppm) and ethylene absorbent treatment.

Zhang *et al.* (1991) reported a reversal of delay in ripening by enclosing an ethylene absorbent by a CO_2 absorbent. Li *et al.* (1991) studied the effects of a complex preservative containing 1000ppm thiophonate, 2000ppm Urea. 2000ppm KH_2PO_4 and 40ppm 2,4 D and stored in polyethylene bag containing ethylene absorbent, at 29±1.7°C remained fresh for 8-18 days than the fruits treated only with thiophonate.

Jayaraman and Raju (1992) developed a self stable and cost effective granulated ethylene scrubber based on potassium permanganate impregnated in an inert matrix formulated using alumina and lime stone and evaluated against scrubber matrices like cement and silica gel. The alumina based formulation was found to be better. It was reported that bananas stored at ambient temperature using scrubber sachets showed an overall extension in shelf-life ranging from 3-8 days and the alumina and cement based scrubber were economical when compared to imported trade product. Lin and Zhang (1993) reported that fruits of 75-80% maturity when packed in polybags of 0.07 thickness with 10 kg fruits and 80g $KMnO_4$ amargosite, sealed and stored at room temperature had an extended green-life.

Mohammed and Campbel (1993) reported maximum percentage of marketable fruits after 12 days in LDP.E. and $KMnO_4$ treated fruits and fruits stored at 20°C in LDPE bag with $KMnO_4$ scored the highest overall quality.

Sadhu and Gupta (1997) reported that Triazole application delayed ripening and reduced cellulose and polygalacturanase activity during the ripening and Bas 111.W (a triazole derivative) was also found to be effective in inhibiting ethylene production. Sisler *et al.* (1997) reported that 1-MCP at concentration around 0.7ml/l inhibited ripening and bananas regained sensitivity to ethylene 12 days after treatment with 1-MCP. It was also possible to stop the triggered ripening by application of 1-MCP. Dominguez *et al.* (1998) reported that AUG inhibits endogenous ethylene production and cobalt ions inhibit induced respiration and ethylene production.

Pathak and sanwal *et al.* (1999) reported that fruit ripening based on fruit weight, pulp/peel ratio, pH of fruit pulp, respiration rate and total sugar content at room temperature was accelerated by inorganic pyrophosphate, calcium chloride and 2,4 D and slowed by ascorbic acid, sodium metabisulphate, ferrous sulphate, IAA and GA_3. Jiang *et al.* (1999) reported prevention of ethylene stimulated-ripening in bananas exposed for 12 hr at 20°C to just 50 ml 1-MCP/litre or 1 hr exposure at 20°C to 100 ml 1-MCP/litre.

2.10. Grading

Export oriented bananas are shipped and trucked to ripening room, from where they are either sent directly to the wholesale market in original cartons or pre-packed and labeled for supermarkets. Now with the changing trends, supermarkets have become popular. They provide consumers with produce, which not only excel for the appeal but also for the quality. Supermarkets therefore place great importance on high product and packaging standards and detailed specifications to maintain a high turnover of perishable fruits.

Consumer sees only the ripe fruit, so they expect the fruit to be yellow and skin free from scars, bruises and other defects and ripened to an appropriate stage, at which the eating quality of the fruit is at its best.

In countries like UK, because of the high standard of living and dominance in the fresh fruit trade supermarkets have increased the fruit quality standards demanded by most banana importers in the UK. All major supermarkets have pre-determined specifications. The fruits are pre-packed and priced according to their specifications. The fruits that do not meet the specifications are rejected.

In UK the market prefers long, clean skinned well-packed bananas presented as hands with no latex marks or stains on the skins and with an ideal finger length of 13-23 cm. (E.C.Guidelines, 1994)

In France the quality standards for fruit can be grouped into five categories.

1. Fruits defects tolerated
2. Minimum finger length
3. Minimum and maximum grade
4. Cluster size and arrangement
5. Net box weight

Fruit defects include blemishes that affect the peel and pulp of which scaring and bruising is the most common and serious they are classified and scored as trace, light, medium and severe. Defects affecting the pulp such as bruising are considered critical and given a higher defect rating than blemishes affecting only peel.

The marketed grades in France are broadly described as

- Red – Extra (finest) quality with finger length 17-18 cm
- Green – Middle quality with finger length 15-16cm
- Yellow – Average quality with finger length <14 cm

In Germany, the most competitive banana market in E.C. fruits are preferred as clusters of 4 to 5 bananas with brand labels. Minimum finger length is 20 cm and most bananas sold are in range of 23-26 cm finger length. Bananas smaller are generally not accepted or sold as seconds. The quality of the fruits must be above average. German people being health conscious the fruit must also comply with the MRL (Maximum Residue Levels) ordinance. (E.C.Guidelines, 1994)

Markets in Italy, Denmark, Netherlands and Belgium prefer fruits of top quality with the fruit length range between 23-26 cm.

In Greece the market requirements are

- Consistent quality
- Proven keeping quality
- Consistent size and weight
- Long shelf-life under street vendor condition

The specifications for E.C banana market. (1993) Visual standards.

Banana must be clean and free of latex stains, thrip marks and rust. Minor marks should be light and confined to the back and sides of the clusters of hands. Bruises and large areas of heavy blemish are not acceptable and fruits in this condition will not be paid for.

Fruit length – Fruit should ideally be grouped into 2 sizes large and small.

Large	: Minimum length –	20cm.
	Maximum length –	36cm.
Small	: Minimum length –	11cm.
	Maximum length –	20cm.

The features of banana which are to be taken into account while considering the internal arrangement of the package include:

- Variable size and shape (curvature) of individual.
- Variable number of fruits in a hand or cluster.
- Hard 'crown' with sharp edges, to which the individual fruits are attached.
- Moderately susceptible to impact bruising.
- Skin susceptible to puncture.
- Skin susceptible to abrasion damage.
- Damage which appears minimal on the unripe fruit is much more obtrusive after ripening or as the fruit ages.

The market will not accept single bananas as good quality fruit, individual bananas, therefore, cannot be graded by size. As the smaller hands are found at one end of stem selection of the clusters is possible to some degree, but in general there will be a range of fruit sizes within one box. In the "standard pack" the fruit is over 7.5" long and in 'small banana pack fruits range from 5.5 to 7.5" (Charles and New, 1996).

In Maharashtra, the leading producer of banana in India, generally fruits are graded visually at the unloading site mostly on basis of weight of the bunch and number of hands/bunch and graded as 'A' and 'B'. 'A' grade bunch weighing 15-20Kg and 'B' 10-15Kg. 'A' grade is sent to distant market and 'B' for marketing within Maharashtra and 'C' grade and rejected bunches are sold in local market (Wasker and Roy, 1993).

Grade is one of the most variable of qualities factors, and grade specifications are frequently changed depending on demand and availability of fruit. For fruit in containers from Honduras to United States Gulf ports the average grade in the box ranges from 13 to 14 "(35.7-36.5 mm), where as pacific coast banana fruit that must transit the panama canal has an average grade of 10-11" (33.3-34.1mm). The lowest grade shipped in international trade is to Japan from the Philippines. Japanese regulations allow little or no ripe or turning fruit hence the grade averages only 9-10" (32.5-33.3mm).

Materials and Methods

MATERIALS AND METHODS

The present investigation on Postharvest handling and packaging systems for 'Nendran' *Musa* (AAB) was carried out at the Department of Processing Technology. College of Horticulture, Vellanikkara, Thrissur, Kerala during 1998-2000.

The research programme was divided into four experiments.

- Studies on ripening of banana *Musa* (AAB) 'Nendran'
- Development of suitable technique for extension of shelf-life of banana *Musa* (AAB) 'Nendran'
- Development of packages for retail marketing of banana *Musa* (AAB) 'Nendran'
- Development of grading system for banana *Musa* (AAB) 'Nendran'

'Nendran' the most popular banana variety of Keralites is known all over the world as "Pink French plantain". The fruit is cooked to make it more palatable. They are also used for preparing various dishes. 'Nendran' banana chips are a very popular snack food for keralites. 'Nendran' fruits are long cylindrical, 22 to 25 cm in length about 12.5 cm on girth, with a slight curve at the middle or almost straight, irregularly five sided, apex short but distinct apex, thick and leathery skin, firm pinkish pulp, with fairly conspicuous core and has mildly pleasant flavour and medium sweet taste.

- Acquisition of fruits

'Nendran' bunches were collected from Banana Research Station, Kannara. Bulk 'Nendran' crops were maintained as per the Package of Practice Recommendations (K.A.U., 1996).

The bunches were harvested when the plant showed drying of the top leaves, and the fruits showed a change of skin colour to light green .At this stage floral ends turned brittle .The bunches after harvest were carefully transported on the same day to the laboratory (Plate 1). Hands free from injuries were selected and used for different treatments of the experiments.

3.1. Experiment I – Studies on ripening of banana *Musa* (AAB) 'Nendran'

The experiment was aimed at evaluating the postharvest behaviour of 'Nendran' under ambient conditions with seven treatments in four seasons. (i.e. August 1999; November 1999; February 2000; and May 2000). The temperature and relative humidity prevailed during the period of study from 1998 to 2000 is shown in Appendix-1.

3.1.1. Experiment details

Bunches of uniform maturity were harvested and from them hands of uniform size were separated and pooled. The hands were selected at random and used for different treatments on the same day of harvest.

Treatments

T_1- 'Nendran' banana hands stored in smoke filled chamber for 24 hours and after wards stored in open condition.

T_2- 'Nendran' banana hands stored in smoke filled chamber for 48 hours and afterwards stored in open condition.

T_3- 'Nendran' banana hands stored in smoke filled chamber for 72 hours and after wards stored in open condition.

T_4- 'Nendran' banana hands stored after wrapping in dry banana leaves and kept in open condition.

Plate 1. 'Nendran' banana bunch

T_5- 'Nendran' banana hands stored under ethylene vapour filled chamber for 48 hours and afterwards kept in open condition.

T_6- 'Nendran' banana hands stored under open condition after dipping in ethrel solution of 1000 ppm.

T_7- 'Nendran' banana hands stored under open condition.

Replications – 3

Design – CRD

The experiment was repeated in four seasons, viz: August – 1999, November – 1999, February –2000, and May – 2000.

The room in which, the fruits of different treatments were kept were well ventilated. The set of treatments were physically separated from one another as far as possible to avoid any possible influence on the neighboring treatments.

Extra replications were also arranged in each treatment to gather the data trough destructive sampling and also for recording the physiological loss in weight.

- Smoke Chamber

The smoke chamber consisted of a transparent air-tight plastic box of ten liters capacity in which the unripe fruits were placed and smoked using a smoker till the entire box was filled with smoke and then sealed (Plate 2). The banana hands were taken out and kept at ambient conditions after 24, 48 and 72 hours respectively in treatments T_1, T_2, and T_3

- Ethylene vapour chamber

Ethylene vapour chamber consisted of a transparent air-tight plastic box of ten-liter capacity in which the unripe fruits were placed along with a small beaker containing 10 ml of 5000ppm ethrel to which 2 g of sodium hydroxide was added and sealed. The hands were taken out and kept at ambient conditions after 48 hours.

3.1.2. Observations

3.1.2.1. Physical parameters

3.1.2.1.1. Physiological loss in weight (PLW)

PLW was calculated on the initial weight basis at six day interval and expressed in percentage.

$$\text{PLW}(\%) = \frac{\text{Initial wt.} - \text{Wt. after storage}}{\text{Initial wt.}} \times 100$$

3.1.2.1.2. Number of days for half-ripe stage

Number of days taken by the fully mature green fruit from date of harvest to reach full yellow stage but not tuned soft when pressed with fingers. This is considered as the green-life of the fruit.

3.1.2.1.3. Number of days for full-ripe state

Number of days taken by the fully mature green fruit from the date of harvest to reach full yellow stage and with a soft texture when pressed with fingers. This fruit is considered to be in the edible condition.

3.12.1.4. Shelf-life

Number of days taken by the fruit from the half-ripe stage to the unmarketable stage. Unmarketability was attributed when more than 50% of the fruits in a banana hand showed less than 50% blackening as spots, specks and lesions.

3.1.2.1.5. Marketability

Fruits were considered to be in marketable grade when more than 50% of the fruits in a hand show less than 50% blackening as specks and lesions.

Marketability was calculated based on cumulative spoilage and PLW (On Wuzulu *et al.*, 1995).

%Marketable fruits = 100 – (% spoilage + PLW)

3.1.2.2. Biochemical Parameters

The replications intended for destructive sampling were used to estimate. T.S.S, Titrable acidity, Brix:acid ratio, total sugars, reducing sugars and starch content of fruits.

3.1.2.2.1. Total soluble solids (T.S.S)

T.S.S was determined by using Erma hand held refractrometer (range O-32 brix) and expressed in degree brix.

3.1.2.2.2. Titrable acidity

Titrable acidity was estimated by adopting the method of A.O.A.C (1980). Ten grams of the macerated sample was digested with boiling water and made up to a known volume. An aliquot of the filtered solution was titrated against O.I.N NaOH using Phenolphthalein as indicator. The acidity was expressed as percent of Mallic acid.

3.1.2.2.3. Brix: acid ratio

The ratio was determined by dividing the degree brix of the sample by the percentage of titrable acidity of the sample and was expressed nearest to third decimal place (Ranganna, 1986).

3.1.2.2.4. Reducing sugar

Reducing sugar content was determined by adopting the method given by Lane and Eynon (Ranganna, 1986). To ten grams of the fruit pulp, distilled water was added and after thorough mixing, the solution was clarified with neutral lead acetate. Excess lead acetate was removed by adding potassium oxalate and volume was made up to 250ml. The solution was filtered and an aliquot of this solution was titrated against a mixture of Fehlings solution A and B using methylene blue as indicator. The reducing sugar was expressed in percentage.

3.1.2.2.5. Total sugars

Total sugar content was determined by adopting the method given by Lane and Eynon (Ranganna, 1986). Clarified solution of 50ml was boiled gently after adding citric acid and water. It was neutralized with NaOH and volume made up to

250 ml. The made up solution was titrated with a mixture of Fehlings solution A and B and the total sugar content was expressed in percent.

3.1.2.2.6. Starch

Starch content was determined by colorimetric method using anthrone reagent as proposed by Sadasivam and Manickam (1997) Powdered and dried sample (0.2g) was homogenized in eighty percent ethanol and centrifuged, to remove the sugars, the residue was retained and washed repeatedly with hot eighty percent ethanol. The residue was dried over water bath and to this 5ml water and 6.5ml of 52% perchloric acid was added and extracted at 0°c centrifuged for 20 min. and the supernatent was saved. The extraction was repeated using fresh perchloric acid. The supernatants were pooled and made up to 100ml. 0.1ml of the supernatent was pipetted and made up to 1ml. To this 4ml of Anthrone reagent was added and heated for 8 min., cooled rapidly and the intensity of green colour was read at 630 nm in a spectronic 20 spectrophotometer. A standard graph was prepared using serial dilution of standard glucose solution. From the standard graph, glucose content of the sample was obtained and concerted to fresh weight basis. This value was multiplied by a factor of 0.9 to arrive at the starch content.

3.1.2.2.7. Organoleptic evaluation

The organoleptic evaluation for assessing the colour, flavour, and taste of ripe fruits after storage was done by a panel of ten members using a ten point hedonic scale. The ratings were as follows:

0-2 – Poor
3-5 – Satisfactory
6-8 – Good
9-10 – Excellent

3.2. Experiment II – Techniques for Extension of shelf-life of banana *Musa* (AAB) 'Nendran'

The experiment was aimed at development of suitable technique(s) for extension of shelf-life of 'Nendran' banana fruits. The experiment comprised of five treatments meant for extending the shelf-life under three storage conditions (i.e.) 13°c, 18°c, Ambient.

3.2.1. Experiment details

Treatments were as follows:

Fully mature fruits immediately after harvest were used for the experiment.

T_1 – Control. ('Nendran' banana hands stored under ambient condition)

T_2 – 'Nendran' banana hands stored with ethylene absorbent.

T_3 – 'Nendran' banana hands stored after precooling with cold water @ 15°c for ten minutes.

T_4 – 'Nendran' banana hands stored after precooling with ice flakes for five minutes.

T_5 – 'Nendran' banana hands stored after treating with hot water @ 50°c for ten minutes.

Storage conditon: 13oc, 18°c, ambient temperature

Replications – 4

Design – CRD

- For all the treatments hands of 'Nendran' banana were selected (as explained in 3.1.1) at random and after imposing the appropriate treatment, the hands were placed in air-tight containers. After every seven days of storage a set of fruits were taken out from the storage environment and kept under ambient conditions to study their ripening behaviour. Extra hands were kept under similar storage condition for destructive sampling.

- Preparation of ethylene absorbent

In the laboratory, the ethylene absorbent was prepared by impregnating vermiculite with potassium permanganate. Saturated solution of potassium permanganate was poured into dried vermiculite and left for 30 min. The absorbent mixture was kept in muslin cloth bags and sealed in unglazed soft tissue paper sachets (Plate3). Each sachet contained 10 g of the ethylene absorbent .The absorbent was used at the rate of one sachet / hand.

- Hot water treatments

Water was heated to 50°c in a water bath. 'Nendran' banana hands were packed in a nylon-net bag and it was ensured that the fruits were fully immersed in water .The banana hands were removed from hot water after ten minutes and drained. Then 'Nendran' banana hands were placed in air-tight container.

- Precooling with cold water

Water was cooled in a refrigerator to 15°c.'Nendran' banana hands were packed in a nylon-net bag and it was ensured that the banana hands were fully immersed in water. The hands were removed from water after ten minutes and the water was drained. Subsequently the banana hands were placed in air-tight containers.

- Precooling with iceflakes

Ice flakes were collected from Icematic ice flaking machine and ice flakes were spread all over the banana hands to be cooled (Plate 4). Ice was used at rate of 1:1. A contact time of five minutes was allowed. After draining water, and iceflakes the banana hands were placed in air-tight containers.

For storing the banana hands at 13^0c and 18°c two Caltan B.O.D. incubator, Economy automatic, having a temperature range of 5^0c to 50^0c was used. The R.H. maintained was 55-65 per cent.

The temperature and relative humidity prevailed in ambient condition during the experimental period are given in Appendix-2

3.2.2. Observations

Physical and chemical observations taken were similar to that under 3.1.2.

3.3. Experiment III – Development of packages for retail marketing of banana *Musa* (AAB) 'Nendran'

This experiment was aimed at developing a suitable and convenient retail package, which not only gives physical and physiological protection but also gives good eye appeal to the consumer. The experiment consisted of 14 treatments in three replications each.

Plate 2. 'Nendran' banana subjected to smoke filling

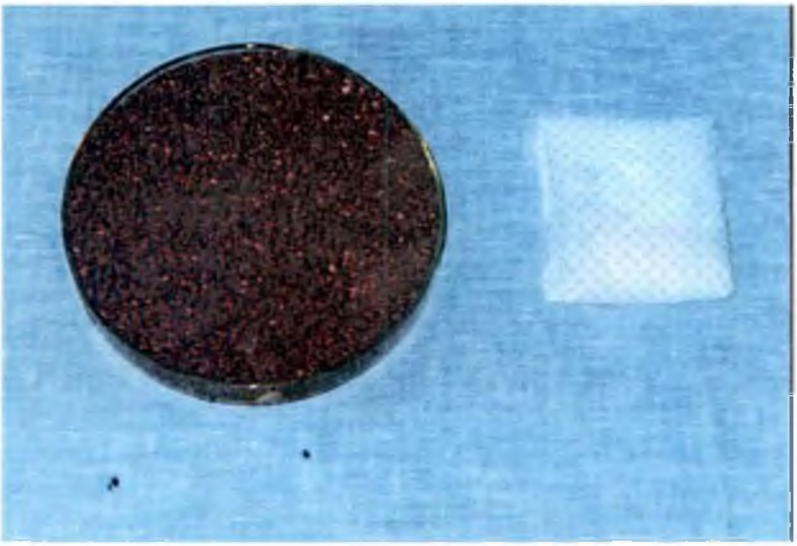

Plate 3. Preparation of ethylene absorbent sachet

3.3.1. Experiment details

'Nendran' bunches of uniform maturity were harvested and from them hands of uniform size were separated and pooled. The hands are selected at random and used for different treatments on the same day of harvest. The treatments include packing with and without ethylene absorbent.

Treatments

T_1 – 'Nendran' banana hands packed in CFB box

T_2 – 'Nendran' banana hands packed in CFB box + polyethylene lining

T_3 – 'Nendran' banana hands packed in CFB box + polyethylene lining + cut ends coated with wax

T_4 – 'Nendran' banana hands packed in CFB box + polyethylene lining + cut ends coated with (Wax + Bavistin)

T_5 – 'Nendran' banana hands packed in ventilated polyethylene bag

T_6 – 'Nendran' banana hands packed in unventilated polyethylene bag

T_7 – 'Nendran' banana hands packed in polyethylene bag under vacuum.

Replication 3

Design - Factorial CRD

- CFB box

Corrugated fiber board box of 5ply, used was of 30 × 25 × 20 L×W×H; where L= Length in cm , W= width in cm ,H= height in cm.

- Polyethylene (P.E) lining was provided by wrapping the hands with a Polyethylene sheet of 100 guage thickness (Plate 5) and of length 60 cm and breadth 60 cm.

- Coating at cut ends of banana hands

The cut ends of banana hands were immersed in Waxol-12%, an aqueous wax emulsion (Dalal, 1971) and dried. Then the banana hands were wrapped in polyethylene sheet of 100 guage thickness.

- Coating of cut ends with (Waxol-12% + Bavistin (1000 ppm)).

Bavistin @ 1000 ppm (carbendizin 50% w.p.) was dissolved in Waxol-12% solution. This solution was used for dipping the cut ends of the 'Nendran' banana hands for one minute and then dried and packed.

- Ventilated polyethylene bag

Banana hand was packed in a transparent low-density polyethylene bag of 100 gauage thickness and of 35 × 25 cm L×B where L = length in cm and B = breadth in cm with uniform ventilation of 2%(Plate 6).

- Unventilated polyethylene bag

Banana hand was packed in a transparent low-density polyethylene of 100 guage thickness (Plate 7) and of 35 × 25 cm L×B where L = length in cm and B = breadth in cm.

- Vacuum pack

Banana hand was placed in a polyethylene bag of 35 × 25 cm L×B where L = length in cm and B = breadth in cm. The polyethylene bag was sealed leaving a small opening of the size of the suction tube using a electric sealing machine. The

Plate 5. 'Nendran' banana packaged in CFB box with polyethylene lining

Plate 6. 'Nendran' banana packaged in (2%) ventilated polyethylene bag

Plate 7. 'Nendran' banana packaged in unventilated polyethylene bag

Plate 8. 'Nendran' banana packaged under vacuum

suction tube of the vacuum pump was placed in the opening of the polyethylene bag and the vacuum pump was put on. After the vacuum is created inside the polyethylene bag indicated by the collapse of the polyethylene bag around the fruit the opening was sealed and the vacuum pump was put off. Vacuum pump used was Tosniwal High Vacuum pump ¼ H.P. motor with a capacity of 100 lit/min (Plate 8).

Another set of all above treatments was also prepared. In all the packs one sachet of absorbent was placed. The preparation of ethylene absorbent is given in 3.2.1.

The packages were kept in ambient condition and the temperature and relative humidity prevailed during the experimental period are given in Appendix – III.

3.3.2. Observations

Physical and biochemical observations taken were similar to that followed in 3.1.2.

3.4. Experiment IV – Development of a grading system for banana *Musa* (AAB) 'Nendran'

This experiment was aimed at suggesting a grading system for 'Nendran' that can be of use to farmers, consumers and traders. Bunches harvested according to the prescribed harvest maturity were taken and the variation in the following parameters were worked out between the first and last hand of the bunch. Appropriate statistical techniques were tried to develop grade standard for use as a guide during retail marketing of 'Nendran' banana.

3.4.1. Observations

3.4.1.1. Hand observations

3.4.1.1.1. Number of fingers

The number of fingers in each hand were counted separately in all bunches from first hand to last hand.

3.4.1.1.2. Weight of hand

Individual hands were separated from the bunch and weighed on counterpoise balance up to one gram accuracy and the weight was expressed in grams.

3.4.1.2. Finger observations

3.4.1.2.1. Fruit length

The length was measured along the convex curve of the finger from the point of pedicel attachment to the top of the fruit and expressed in cm.

3.4.1.2.2. Maximum girth

Maximum girth was taken at the midpoint of the fruit using a twine and measuring scale and expressed in cm.

3.4.1.2.3. Curvature of fruit

Curvature of fruit was calculated by taking the ratio of the outside length of the fruit to the inside length.

Lo/Li   Lo – length of out side

Li – length of inside

3.4.1.2.4. Fruit weight

Weight of individual finger was taken on a counterpoise balance of one gram accuracy and mean expressed in grams.

The general appearance of each hand was scored using the ten point hedonic scale as given in 3.1.2.2.7. Mean values of the physical parameters were compared with the sensory scores.

3.5. Statistical analysis

Observations under each experiment were tabulated and analysed statistically by analysis of variance. The significance was tested by 'F' test. The standard error and critical difference at 5 per cent probability level were worked out.

In case of where the data could not be recorded due to unmarketable condition of the hands, the characters were analysed through the "non-ortho" option in Mstat C programme.

In experiment III involving packaging with and without ethylene absorbent the data were analysed in a factorial CRD and in case where the data could not be recorded due to unmarketable condition of hands, the characters were analysed using simple CRD instead of factorial design.

The scores of organoleptic evaluation were analysed by Kruskal Wallis – One-way analysis of variance.

In experiment 4 involving development of a grading system for 'Nendran' banana, the significance of physical parameters and score for general appearance between different hands was tested by using paired 't' test.

Results

RESULTS

The results of the studies conducted in the Department of Processing Technology, College of Horticulture, Vellanikkara during 1998-2000 under the project postharvest handling and packaging systems for banana *Musa* (AAB) 'Nendran' are presented in this chapter under the following heads:

4.1. Studies on ripening of banana *Musa* (AAB) 'Nendran'.

4.2. Development of suitable technique(s) for extension of shelf-life of banana *Musa* (AAB) 'Nendran'.

4.3. Development of packages for retail marketing of banana *Musa* (AAB) 'Nendran'.

4.4. Development of a grading system for banana *Musa* (AAB) 'Nendran'.

4.1. Experiment I – Studies on ripening of banana *Musa* (AAB) 'Nendran'

Postharvest behaviour of 'Nendran' under ambient conditions subjected to seven postharvest treatments were evaluated in four seasons of a year (i.e. August, 1999; November, 1999; February; 2000, and May, 2000). Observations were recorded on physical and chemical parameters. The results obtained are presented below.

4.1.1. Physiological loss in weight (PLW) of 'Nendran' in different seasons due to storage under ambient conditions

The PLW on the sixth and twelfth day are presented in Table 1. The treatments differed significantly in PLW on the sixth day in all the seasons. Hands wrapped in dry banana leaves (T_4) recorded the lowest PLW on all the days of observation in all the seasons and the hands stored in smoke filled chamber for 24 hrs (T_1) and ethylene vapour filled chamber (T_5) recorded the maximum PLW.

In August and November, treatments differed significantly in PLW on the sixth and twelfth days. On the sixth day, in August, maximum PLW (15.83%) was recorded by the hands dipped in ethrel (1000ppm) solution (T_6) where as in November the hands stored in smoke filled chamber for 24 hours (T_1) recorded the maximum PLW (10.24%). On twelfth day of storage under ambient condition in August, 1999 hands stored in smoke filled chamber for 24 hrs (T_1) recorded the maximum PLW (25.43%) and in November it was by the control (T_7) (14.77%).

In February and May, 2000; the treatments differed significantly only on the sixth day. In February 2000 hands dipped in ethrel (1000ppm) solution (T_6) recorded the maximum PLW (15.63%) and in May, banana hands in control treatment recorded the maximum PLW (9.40%).

4.1.1.2. Days to ripening

4.1.2.a. Number of days to half-ripe stage

Number of days taken by the fully mature green fruit to reach full yellow stage but not turned soft when pressed with fingers is recorded as the number of days to half-ripe stage. This is considered as the green-life of the fruit.

The days to half-ripe stage differed significantly (Table 2) in all the seasons. The maximum days to reach half-ripe stage was recorded by the hands wrapped in dry banana leaves (T_4) (11.33, 9.66, 12.00 and 10.33 days respectively in August, November, February and May) which show the usefulness of wrapping in dry banana leaves as a traditional living material followed by control (T_7) (9.00, 5.67, 10.00 and 7.33 days respectively in August, November, February and May).

Table1. Effect of postharvest treatments on PLW in different seasons

Season / Treatments	Physiological loss in weight (PLW) %							
	August		November		February		May	
	Duration of storage (days)		Duration of storage (days)		Duration of storage (days)		Duration of storage (days)	
	6	12	6	12	6	12	6	12
T_1	14.07	25.43	10.24	ND	12.69	ND	9.27	ND
T_2	10.40	21.70	7.07	ND	14.55	ND	7.94	ND
T_3	8.30	17.57	9.57	ND	15.11	ND	7.31	ND
T_4	7.63	10.79	8.63	10.79	6.03	11.9	6.75	12.83
T_5	9.33	ND	8.63	ND	12.80	ND	6.92	ND
T_6	15.83	ND	9.31	ND	15.63	ND	8.37	ND
T_7	8.57	14.67	10.07	14.77	6.67	13.13	9.71	14.67
CD (P=0.05)	1.75	2.43	1.76	5.17	3.28	N.S	1.86	N.S

ND – Not determined due to termination of storage

NS – Not significant at 5% level

Table 2. Effect of postharvest treatments on days to ripening in different seasons

Season / Treatments	August		November		February		May	
	Half ripe	Full ripe	Half ripe	Full ripe	Half ripe	Full ripe	Half ripe	Full ripe
T_1	2.67	5.33	2.00	3.67	2.67	4.67	1.33	3.33
T_2	3.33	5.33	2.33	4.67	3.67	5.67	2.00	4.33
T_3	3.00	6.33	2.33	5.00	4.67	7.33	3.33	6.33
T_4	11.33	13.67	9.67	11.67	12.00	15.00	10.33	13.00
T_5	2.33	4.33	2.33	4.33	2.67	4.67	1.67	4.33
T_6	2.67	4.33	2.00	3.33	2.67	4.33	1.33	3.33
T_7	9.00	11.00	5.67	10.00	10.00	13.00	7.33	9.67
CD (P=0.05)	1.27	1.48	1.26	1.57	1.27	1.71	0.94	1.15

4.1.2.b. Number of days to full-ripe stage

Days taken by the mature green fruit to reach edible ripe stage are considered as the number of days to full-ripe stage.

The treatments differed significantly in the days to full-ripe stage in all the seasons and showed a result similar to the days to reach half-ripe stage.

The treatments involving smoke treatment (T_1, T_2, T_3) and ethrel (T_5 and T_6) did not differ significantly in the days to reach half-ripe and full-ripe stages and the bananas were found to attain full-ripe stage in two to three days after the half-ripe stage and smoke treatments (T_1, T_2, T_3) ethrel treatments (T_5 and T_6) can, therefore, be considered as effective ripening agents (Plate 9).

4.1.4. Marketability of 'Nendran' banana in different seasons as influenced by postharvest treatments

The fruits are said to be marketable when they are in the edible condition (i.e.) from the full-ripe stage till more than 50 per cent of the fruits show more than 50 per cent of blackening on skin due to specks, spots and lesions.

Marketability was significantly influenced by different postharvest treatments on the third day (Table 3). Marketability did not differ between the seasons. In August, November and February, banana hands dipped in ethrel solution (T_6) recorded the lowest marketability (44.37%, 43.96% and 43.23% respectively) and all the other treatments were on par to it. In May 'Nendran' hands stored in smoke filled chamber for 24 hours (T_1) recorded the lowest marketability (70.17%).

Table 3. Effect of postharvest treatments on marketability percentage in different seasons

Season / Treatments	Markatability (%)							
	August		November		February		May	
	Duration of storage (days)		Duration of storage (days)		Duration of storage (days)		Duration of storage (days)	
	3	6	3	6	3	6	3	6
T_1	85.93	ND	89.77	ND	81.31	ND	70.17	ND
T_2	89.60	ND	92.93	ND	84.63	ND	92.06	ND
T_3	91.70	49.50	90.47	ND	84.89	ND	93.00	ND
T_4	92.37	89.21	91.37	84.17	93.97	88.10	93.12	87.17
T_5	89.83	ND	90.67	ND	87.20	ND	84.17	ND
T_6	44.37	ND	43.96	ND	43.27	ND	77.63	ND
T_7	91.43	79.47	89.93	79.70	93.33	85.77	87.63	81.17
CD(P=0.05)	6.15	18.74	4.35	N.S	9.54	N.S	10.11	N.S

ND – Not determined due to termination of storage

NS – Not significant at 5% level

Banana hands wrapped in dry banana leaves (T_4) and control (T_7) recorded marketability up to sixth day in all the seasons, and the two treatments did not differ significantly in marketability.

4.1.5. Chemical changes at different stages of ripening in different seasons in 'Nendran' banana.

Analysis of variance of chemical constituents like T.S.S, acidity, Brix:acid ratio, total sugars, reducing sugars and starch at different stages of ripening viz half-ripe, full-ripe and degradative stage in different seasons Viz. August, November, February and May (1999-2000) are presented below (Table 4a and 4b).

4.1.5.1. Total soluble solids (T.S.S)

During ripening of banana starch is converted to lower sugars. This change is reflected in the T.S.S value of fruits.

The T.S.S content at the full-ripe stage differed significantly between the treatments in all the seasons except November. The maximum T.S.S content was recorded by the hands dipped in ethrel (1000ppm) solution (T_6), in all the seasons. The T.S.S at full-ripe stage ranged from 27.33 to 30.67°Brix.

In degradative stage (i.e.) when the fruits become unmarketable, the treatments differed significantly in T.S.S content in February and May. In February hands dipped in ethrel (1000ppm) solution (T_6) recorded the maximum T.S.S (27.33°Brix) and in May hands stored for 24 hours in smoke chamber (T1) recorded the maximum T.S.S (28.67°Brix). At degradative stage T.S.S ranged from 24.33-28.67°Brix.

Table 4a. Effect of postharvest treatment on acidity, T.S.S and brix/acid ratio of banana fruits

Season / Treatments	August								
	Half ripe			Full ripe			Degradative stage		
	Acidity (%)	T-SS (°brix)	B/A	Acidity (%)	T-SS (°brix)	B/A	Acidity (%)	T-SS (°brix)	B/A
T_1	0.45	21.67	53.90	0.56	29.00	51.85	0.41	24.67	62.74
T_2	0.41	23.67	60.00	0.39	27.67	62.08	0.44	26.00	60.08
T_3	0.45	19.50	50.52	0.47	27.67	61.93	0.49	26.33	54.39
T_4	0.47	25.00	57.46	0.41	27.33	69.39	0.40	26.33	69.65
T_5	0.45	24.00	57.19	0.42	27.67	68.17	0.46	25.00	54.40
T_6	0.45	23.00	51.82	0.50	30.67	62.52	0.45	27.67	63.02
T_7	0.57	24.00	42.30	0.45	30.00	67.63	0.45	27.33	61.83
CD (P=0.05)	N.S	N.S	N.S	N.S	1.95	N.S	N.S	N.S	N.S

NS – not significant at 5% level
B/A – Brix : acid

Season / Treatments	November								
	Half ripe			Full ripe			Degradative stage		
	Acidity (%)	T-SS (°brix)	B/A	Acidity (%)	T-SS (°brix)	B/A	Acidity (%)	T-SS (°brix)	B/A
T_1	0.35	23.00	67.80	0.43	28.67	69.30	0.39	26.00	68.74
T_2	0.39	23.00	61.10	0.57	28.67	51.80	0.36	24.33	69.42
T_3	0.43	21.67	54.62	0.52	29.33	56.52	0.46	25.00	54.93
T_4	0.45	23.33	56.02	0.50	28.33	56.31	0.45	25.00	59.73
T_5	0.41	24.33	62.13	0.39	27.67	73.39	0.43	25.67	61.41
T_6	0.53	24.00	45.90	0.51	29.33	57.23	0.43	26.67	62.22
T_7	0.53	22.67	44.16	0.53	29.33	56.66	0.36	27.00	76.28
	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S	N.S

NS – not significant at 5% level
B/A – Brix : acid

Table 4a. Contd...

Season / Treatments	February								
	Half ripe			Full ripe			Degradative stage		
	Acidity (%)	T-SS (°brix)	B/A	Acidity (%)	T-SS (°brix)	B/A	Acidity (%)	T-SS (°brix)	B/A
T_1	0.41	24.67	62.13	0.57	29.33	51.83	0.44	25.33	59.53
T_2	0.47	23.67	53.53	0.52	30.33	58.61	0.44	25.00	58.93
T_3	0.43	23.67	57.21	0.46	27.67	60.96	0.47	24.67	53.43
T_4	0.49	24.00	54.00	0.52	27.33	52.95	0.47	24.33	52.50
T_5	0.37	22.67	63.15	0.44	28.33	67.07	0.49	25.00	54.40
T_6	0.40	24.00	62.40	0.55	30.67	56.25	0.42	27.33	67.17
T_7	0.47	25.00	57.46	0.53	28.00	52.52	0.55	25.67	46.90
CD (P=0.05)	N.S	N.S	N.S	N.S	1.98	N.S	N.S	1.71	N.S

NS – not significant at 5% level
B/A – Brix : acid

Season / Treatments	May								
	Half ripe			Full ripe			Degradative stage		
	Acidity (%)	T-SS (°brix)	B/A	Acidity (%)	T-SS (°brix)	B/A	Acidity (%)	T-SS (°brix)	B/A
T_1	0.39	22.00	58.57	0.52	29.67	57.63	0.46	28.67	64.46
T_2	0.35	22.67	66.85	0.44	28.33	65.00	0.48	25.33	56.31
T_3	0.32	23.33	80.91	0.47	27.67	59.10	0.47	24.33	52.57
T_4	0.41	23.33	56.52	0.45	28.67	60.62	0.49	25.00	51.62
T_5	0.45	24.33	55.35	0.46	28.67	65.10	0.36	26.33	75.56
T_6	0.46	18.00	55.82	0.55	30.67	56.29	0.48	27.00	56.88
T_7	0.42	23.67	60.12	0.41	27.33	69.39	0.50	25.67	52.20
CD (P=0.05)	N.S	N.S	N.S	N.S	1.53	N.S	N.S	1.83	N.S

NS – not significant at 5% level
B/A – Brix : acid

4.1.5.2. Acidity

The acidity content was not significant at any of the stages of ripening in different seasons. Acidity value of fruit pulp ranged from 0.32-0.57%.

4.1.5.3. Brix :acid ratio

The Brix:acid ratio has a specific influence on the taste of the fruit and a high sugar: acid ratio indicates a better sugar:acid blend.

The brix:acid ratio in the different treatments did not differ significantly at any stage of ripening and in any seasons. The brix:acid ratio ranged between 42.29 and 80.00.

4.1.5.4. Total sugar

The treatments differed significantly in total sugar content at half-ripe stage in all the seasons. In August, February and May the total sugar recorded by banana hands wrapped in banana leaves (T_4) and control (T_7) were on par with the other treatments. In November banana hands stored in ethylene vapour chamber (T_5) recorded the maximum total sugars (17.25%) followed by those wrapped in dry banana leaves (T_4) and control (T_7). The total sugars ranged between 5.99 and 17.26%.

At full-ripe stage the total sugar content differed significantly between the treatments only in February. Control (T_7) recorded the maximum total sugars (21.64%) and the total sugars ranged between 13.65 and 20.85%.

At degradative-stage the treatments differed significantly in total sugar content in all seasons except in November. The total sugar content did not follow a particular trend and it ranged between 10.61 – 20.34%.

4.1.5.5. Reducing sugar

The reducing sugar content was influenced significantly by the treatments at half-ripe stage only in November. Banana hands stored in ethylene vapour chamber (T_5) recorded the maximum reducing sugar content (6.55%) and the reducing sugar content at half-ripe stage varied between 2.59 to 6.55%.

At full-ripe stage the treatments differed significantly in reducing sugars in February and May. In February the control (T_7) recorded the maximum (8.31%) which was on par with the reducing sugar content recorded by the hands wrapped in dry banana leaves (T_4) while in May hands wrapped in dry banana leaves (T_4) recorded the maximum (10.11%) reducing sugars.

At degradative stage no significant difference in reducing sugar content was recorded in any season. The reducing sugar content ranged between 3.96- 9.58%.

4.1.5.6. Starch

Hydrolysis of banana starch is the major change occurring during ripening of 'Nendran' banana.

Starch content was not influenced significantly by the treatments at half-ripe and degradative stages in any season. Starch content ranged from 20.53 to 34.01% at half-ripe stage and 3.88- 9.08% at degradative stage.

Table 4b. Effect of postharvest treatments on total sugar, reducing sugar and starch content of banana in different seasons

Season / Treatments	August								
	Half ripe			Full ripe			Degradative stage		
	T.S. (%)	R.S (%)	Starch (%)	T.S. (%)	R.S (%)	Starch (%)	T.S. (%)	R.S (%)	Starch (%)
T_1	6.69	3.16	30.28	17.97	5.62	14.80	14.78	4.50	5.42
T_2	8.79	3.28	29.75	17.81	6.94	13.92	15.56	6.10	4.76
T_3	12.52	3.59	34.01	19.44	6.40	12.72	17.96	9.59	5.79
T_4	14.82	4.50	33.92	20.64	9.25	12.12	19.56	7.36	5.97
T_5	14.48	4.96	27.23	18.97	8.26	14.50	17.86	7.38	6.85
T_6	13.98	4.42	32.35	19.29	8.50	13.13	20.27	8.00	7.17
T_7	14.60	4.21	33.65	19.76	9.87	12.10	17.36	6.91	7.02
CD (P=0.05)	1.92	N.S	N.S	N.S	N.S	N.S	2.27	N.S	N.S

NS – not significant at 5% level
T.S. – Total sugars
R.S. – Reducing sugars

Season / Treatments	November								
	Half ripe			Full ripe			Degradative stage		
	T.S. (%)	R.S (%)	Starch (%)	T.S. (%)	R.S (%)	Starch (%)	T.S. (%)	R.S (%)	Starch (%)
T_1	7.72	2.84	23.43	17.64	6.48	12.40	17.95	6.40	3.88
T_2	8.89	2.70	20.53	18.49	7.23	14.88	14.91	5.56	7.33
T_3	7.54	3.71	27.78	18.22	7.48	12.64	14.12	4.26	6.28
T_4	14.99	5.60	32.72	20.58	8.84	16.12	16.61	5.79	5.83
T_5	17.26	6.55	26.67	19.06	6.12	11.85	16.40	5.86	6.98
T_6	10.33	3.82	33.18	19.78	7.53	12.79	16.04	5.19	4.76
T_7	14.90	4.64	28.70	19.70	9.99	18.62	17.34	4.69	5.92
CD (P=0.05)	1.39	2.18	N.S	N.S	N.S	3.97	N.S	N.S	N.S

NS – not significant at 5% level
T.S. – Total sugars
R.S. – Reducing sugars

Table 4b Contd…

Season / Treatments	February								
	Half ripe			Full ripe			Degradative stage		
	T.S. (%)	R.S (%)	Starch (%)	T.S. (%)	R.S (%)	Starch (%)	T.S. (%)	R.S (%)	Starch (%)
T_1	8.55	2.95	23.72	18.88	6.08	17.18	14.95	4.30	5.68
T_2	9.11	3.26	22.78	14.53	5.05	13.33	14.64	3.96	9.08
T_3	5.99	2.60	25.93	16.76	7.53	13.75	10.61	4.44	6.62
T_4	15.34	4.72	28.33	20.39	7.72	14.33	16.40	4.72	7.95
T_5	6.35	3.07	24.99	14.12	4.54	14.17	16.32	4.60	6.93
T_6	8.87	3.60	28.27	13.65	4.55	15.85	18.59	5.97	5.50
T_7	14.02	4.80	24.88	21.64	8.31	14.67	17.25	4.27	6.75
CD (P=0.05)	1.79	N.S	N.S	1.59	2.59	N.S	3.59	N.S	N.S

NS – not significant at 5% level
T.S. – Total sugars
R.S. – Reducing sugars

Season / Treatments	May								
	Half ripe			Full ripe			Degradative stage		
	T.S. (%)	R.S (%)	Starch (%)	T.S. (%)	R.S (%)	Starch (%)	T.S. (%)	R.S (%)	Starch (%)
T_1	8.58	3.83	26.26	18.76	7.08	18.54	20.34	6.22	5.65
T_2	8.87	3.14	28.50	16.42	5.03	14.08	18.03	4.89	7.73
T_3	9.46	2.92	26.82	19.62	7.57	13.72	15.28	3.97	7.63
T_4	13.78	4.43	27.69	20.85	10.11	12.98	16.92	4.27	7.95
T_5	9.52	3.46	26.69	18.05	5.82	13.05	17.34	4.69	5.98
T_6	14.12	4.47	28.82	19.58	8.79	13.53	18.36	5.39	7.07
T_7	14.92	5.12	24.78	19.17	6.58	13.77	18.83	5.19	7.23
CD (P=0.05)	1.79	N.S	N.S	N.S	2.89	N.S	2.33	N.S	N.S

NS – not significant at 5% level
T.S. – Total sugars
R.S. – Reducing sugars

At full-ripe stage, starch content differed significantly in November and the hands in control recorded higher starch content (18.62%) which was on par with the starch content recorded by the hands wrapped in dry banana leaves (T_4) (16.12%). The starch content ranged between 11.85% and 18.62% at full-ripe stage.

4.1.6. Organoleptic evaluation of 'Nendran' banana as influenced by postharvest treatments in different seasons

4.1.6a. Appearance

The treatments did not differ significantly in the score for appearance in August, November and February (Table 5). In May the treatments differed significantly in the score and the hand kept in ethylene vapour chamber (T_5) recorded the maximum score (7.8) followed by the hands dipped in ethrel solution (T_6) (7.4), and hands stored in smoke chamber for 72 hours (T_3) (7.1). The hands kept in smoke chamber for 24 hours (T_1) and 48 hours (T_2) recorded the same score (6.9) and the hands wrapped in dry banana leaves (T_4) and those in control (T_7) recorded the lowest score (6.6).

The hands ripened in ethylene vapour chamber were found organoleptically superior in appearance.

4.1.6b. Flavour

The treatments differed significantly with respect to flavour in November only and the hands in ethylene vapour chamber (T_5) recorded the maximum score (7.2) for flavour followed by the hands dipped in ethrel solution (1000 ppm) (T_6) (7.1) and the hands stored in smoke chamber for 72 hours (T_3) (7.0). Lowest score recorded was 5.9 by 'Nendran' hands wrapped in dry banana leaves (T_4).

Table 5. Effect of postharvest treatment on organoleptic qualities of 'Nendran' banana in different seasons

Treatments	Organoleptic score															
	Season															
	August'99				November '99				February '00				May '00			
	App	Flv	Taste	O.A	App	Flv	Taste	O.A	App	Flv	Taste	O.A	App	Flv	Taste	O.A
T_1	6.8	5.9	7.2	6.8	7.0	6.6	6.9	6.9	6.8	6.2	7.5	6.6	6.9	6.4	6.9	6.9
T_2	6.9	6.8	7.2	7.1	7.1	6.8	7.4	7.2	6.8	7.0	7.2	7.0	6.9	7.2	7.2	6.8
T_3	7.2	7.1	7.1	6.8	7.6	7.0	6.9	6.8	7.0	6.9	7.6	7.2	7.1	6.6	7.3	6.9
T_4	5.5	6.3	6.6	5.7	5.9	5.9	6.1	5.9	6.0	6.0	7.1	6.2	6.6	6.1	6.0	6.1
T_5	7.8	7.7	7.7	7.8	7.9	7.2	6.7	7.6	7.8	7.8	7.4	7.8	7.8	7.5	7.7	7.7
T_6	8.3	7.3	8.0	7.9	7.8	7.1	7.5	7.8	7.5	7.5	7.9	7.5	7.4	8.2	8.0	7.4
T_7	6.3	6.7	7.3	6.6	6.3	6.3	6.4	6.6	6.5	6.3	6.7	7.5	6.6	6.7	6.4	6.0
Kruskal wallis 'H' value	14.99^{NS}	11.75^{NS}	10.43^{NS}	10.42^{NS}	10.60^{NS}	27.83^{*}	19.93^{*}	20.88^{*}	14.13^{NS}	12.43^{NS}	29.49^{*}	9.22^{NS}	21.09^{*}	11.34^{NS}	20.31^{NS}	16.52^{NS}

* significant at 5% level
NS – Not significant at 5% level
OA – Over all acceptability
App – Appearance
Flv – Flavour

Legend of score
0 – 2 Poor
3 – 5 Satisfactory
6 – 8 Good
9 – 10 Excellent

The trend was similar in the score for flavour in August and February. In May the hands dipped in ethrel (1000 ppm) solution (T_6) recorded the maximum score for flavour (8.2) followed by the hands in ethylene vapour chamber (T_5) (Table 5).

The hands treated with ethrel (T_5 and T_6) were found organoleptically superior with respect to flavour of the fruit.

4.1.6c. Taste

The score for taste differed significantly between the treatments in November and February (Table 5). Hands dipped in ethrel solution (T_6) recorded the maximum score (7.5 and 7.9 respectively) for taste. This was followed by the smoke treatments (T_1, T_2 and T_3) and ethylene vapour chamber (T_5).

The smoke filling treatments (T_1, T_2 and T_3) secured almost similar scores and the hands wrapped in banana leaves (T_4) recorded the lowest score in all seasons except in February where the control recorded the minimum score.

The hands treated with ethrel were found organoleptically superior with respect to taste.

4.1.6d. Overall acceptability

The treatments varied significantly in the score for overall acceptability only in November and the hands dipped in ethrel (1000ppm) solution recorded the higher score (7.8) followed by the hands in ethylene vapour chamber (T_5) (7.6). The hands kept in smoke filled chamber for 48 hours (T_2) recorded the highest score among the smoke filling treatments. The lowest score was recorded by the hands wrapped in dry banana leaves (T_4). The trend was same in August. In February and May, the hands in ethylene vapour chamber (T_5) recorded maximum scores followed by the hands dipped in ethrel solution (1000 ppm) (T_6).

'Nendran' hands treated with ethrel (T_5 and T_6) were found organoleptically superior in overall acceptability.

4.2. Experiment II – Development of suitable techniques for extension of shelf-life of banana *Musa* (AAB) 'Nendran'

4.2.1. Changes in physical characteristics under different storage conditions

4.2.1.1. Physiological loss in weight (PLW)

The PLW was recorded cumulatively at six days intervals in all the three specified storage conditions. PLW was also recorded in hands kept for post -storage studies in open condition after storing in the specified storage atmosphere of 13 °C, 18°C, and in ambient conditions at weekly intervals. The results are presented in table's 6a, 6b, 7a, 7b, 8a and 8b.

The treatments differed significantly with respect to PLW on all the days of observation, when stored a 13°C. On all the days of observation the cumulative PLW recorded by the banana hands stored with ethylene absorbent (T_2) was the minimum till the end of the storage period. Banana hands stored after precooling with ice flakes (T_4) recorded the maximum PLW followed by the control (T_1) (Table 6a).

Banana hands removed from the storage atmosphere of 13°C for post-storage studies and kept in open condition after 7th, 14th, 21st, 28th, 35th and 42nd days showed significant difference in PLW up to sixth week of storage (42 DAS) (Table 6b).

Table 6a. Effect of treatments on PLW of 'Nendran' banana at storage temperature of 13°C

Treatments	Duration of storage (days)								
	6	12	18	24	30	36	42	48	54
T_1 - Control	0.40	0.43	0.70	1.03	1.48	1.88	2.44	2.91	3.63
T_2 - Storage with ethylene absorbent	0.17	0.17	0.36	0.39	0.62	0.89	1.02	1.21	2.43
T_3 - Storage after precooling with cold water	0.30	0.35	0.73	0.87	1.00	1.10	1.83	2.37	2.90
T_4 - Storage after precooling with iceflakes	0.63	0.67	0.90	1.28	1.60	1.92	3.23	4.03	ND
T_5 - Storage after hot water treatment	0.17	0.24	0.54	0.75	1.19	1.28	2.02	2.63	3.13
CD (P=0.05)	0.21	0.15	0.16	0.22	0.83	0.32	0.36	0.38	0.39

ND – Not determined due to termination of storage

Table 6b. Effect of treatments at 13°C storage temperature on PLW of 'Nendran' banana during post-storage in open condition

Treatments	Physiological loss in weight (PLW)%											
	Duration of storage at 13°C (days)											
	7 DAS		14 DAS		21 DAS		28 DAS		35 DAS		42 DAS	
	Duration of storage in open condition (days)		Duration of storage in open condition (days)		Duration of storage in open condition (days)		Duration of storage in open condition (days)		Duration of storage in open condition (days)		Duration of storage in open condition (days)	
	3	6	3	6	3	6	3	6	3	6	3	6
T_1	8.37	11.68	19.01	21.33	12.90	17.53	7.80	21.77	8.17	20.43	10.67	9.93
T_2	6.83	10.47	15.68	19.77	7.40	16.37	5.93	11.37	5.87	9.90	5.03	10.17
T_3	5.54	10.88	13.17	16.45	5.27	10.90	5.37	9.68	7.08	10.55	3.79	10.25
T_4	6.61	14.35	10.89	14.45	11.44	16.51	8.19	14.60	7.39	12.82	8.08	ND
T_5	7.19	13.09	13.23	15.56	7.33	14.63	7.81	13.37	9.50	14.46	14.52	ND
CD (P=0.05)	1.29	1.28	1.88	2.24	1.37	1.44	1.39	2.23	1.61	0.915	1.63	N.S

DAS – Days after storage
ND – Not determined due to termination of storage
NS – Not significant at 5% level

After three days of storage in open condition control (T_1) recorded the maximum PLW and the banana hands precooled in cold water (T_3) the minimum PLW up to 28 DAS. Banana hands stored after hot water treatment (T_5) recorded the maximum PLW on the third day after 35 DAS and 42 DAS at 13°C.

After six days of storage in open condition control (T_1) recorded the maximum PLW from 14 DAS to 35 DAS.

The bananas stored at 18°C also differed significantly in PLW on all the days till the end of storage period (Table 7a). Banana hands stored after precooling with iceflakes (T_4) recorded the maximum PLW on all days till the end of storage life (30^{th} day). The minimum was recorded by the hands stored with an ethylene absorbent (T_2) on all the days till the end of storage life.

Banana hands stored at 18°C and kept for post- storage studies after 14 days of storage differed significantly in PLW (Table 7b) both on third and sixth day of storage in open condition and the hands stored after precooling in cold water (T_3) recorded in maximum PLW (14.53% and 23.92% on third and sixth day respectively). No significant difference in PLW was recorded after 7 and 21 days of storage at 18°C.

Bananas stored in ambient condition in air-tight container showed significant difference in PLW up to 18^{th} day of storage (Table 8a) and the hands precooled in cold water (T_2) recorded the maximum PLW from the 12^{th} (2.23%) to the end of its storage period up to 18^{th} day (4.87%). The least PLW was recorded by the hands stored with ethylene absorbent (T_2) till the end of the storage life. The treatments did not show significant difference in PLW on 24^{th} and 30^{th} day of storage.

Table 7a. Effect of treatments at 18°C storage temperature on PLW of 'Nendran' banana

Treatments	Physiological loss in weight (PLW)%				
	Duration of storage (days)				
	6	12	18	24	30
T_1 - Control	0.93	1.30	2.21	2.48	ND
T_2 - Storage with ethylene absorbent	0.23	0.47	0.70	1.03	1.37
T_3 - Storage after precooling with cold water	1.03	1.21	1.95	2.72	ND
T_4 - Storage after precooling with iceflakes	1.06	1.52	2.14	2.53	3.27
T_5 - Storage after hot water treatment	0.59	0.79	1.82	2.26	ND
CD (P=0.05)	0.19	0.33	0.37	0.46	0.86

ND – Not determined due to termination of storage

Table 7b. Effect of treatments at 18°C storage temperature on PLW of 'Nendran' banana during post-storage in open condition

Treatments	Physiological loss in weight (PLW)%					
	Duration of storage at 18°C					
	7 DAS		14 DAS		21 DAS	
	Duration of storage in open condition (days)		Duration of storage in open condition (days)		Duration of storage in open condition (days)	
	3	6	3	6	3	6
T_1	7.42	16.57	13.70	20.02	ND	ND
T_2	11.40	19.44	9.50	17.08	10.13	16.93
T_3	10.26	16.63	14.53	23.92	ND	ND
T_4	10.05	17.73	8.87	14.75	11.90	21.72
T_5	7.68	14.19	7.63	15.62	ND	ND
CD (P= 0.05)	N.S	N.S	3.14	3.31	N.S	N.S

DAS – Days after storage

ND – Not determined due to termination of storage

NS – Not significant at 5% level

Table 8a. Effect of treatments at ambient storage temperature on PLW of 'Nendran' banana

Treatments	Physiological loss in weight (PLW)%				
	Duration of storage (days)				
	6	12	18	24	30
T_1 - Control	0.87	1.57	2.49	3.53	ND
T_2 - Storage with ethylene absorbent	0.67	1.67	2.36	2.63	4.48
T_3 - Storage after precooling with cold water	1.03	2.23	4.87	ND	ND
T_4 - Storage after precooling with iceflakes	0.23	0.93	1.93	2.53	5.58
T_5 - Storage after hot water treatment	1.20	2.03	2.29	3.10	4.81
CD (P=0.05)	0.59	0.78	0.65	N.S	N.S

ND – Not determined due to termination of storage

NS – Not significant at 5% level

Table 8b. Effect of treatments at ambient storage temperature on PLW of 'Nendran' banana in post-storage in open condition

Treatments	Physiological loss in weight (PLW) %					
	Duration of storage in ambient condition (days)					
	7 DAS		14 DAS		21 DAS	
	Duration of storage in open condition (days)		Duration of storage in open condition (days)		Duration of storage in open condition (days)	
	3	6	3	6	3	6
T_1	10.78	17.15	8.47	14.70	11.20	15.60
T_2	8.87	15.29	6.90	12.55	6.77	11.55
T_3	6.61	ND	7.58	ND	ND	ND
T_4	5.47	9.66	6.50	8.70	9.00	11.55
T_5	8.89	23.73	8.33	14.03	12.17	ND
CD (P=0.05)	1.17	2.92	1.27	3.79	1.64	0.85

DAS – Days after storage

ND – Not determined due to termination of storage

The fruits stored in air-tight container at ambient condition differed significantly on all days of storage in open condition in post-storage studies. Hot water treatment (T_5) recorded maximum PLW (8.89% and 23.72% on the third and sixth day of storage) and the banana hands precooled in ice (T_4) recorded the lowest (5.47% and 9.66% on third and sixth day respectively) after seven days of storage in the storage environment. After 14 days of storage in storage environment control (T_1) recorded maximum PLW and banana hands precooled in iceflakes (T_4) the lowest on both third and sixth day of storage in open condition. After storage for 21 days in the storage environment, hot water treatment (T_5) recorded the maximum PLW on third day and the storage was terminated before the sixth day due to reaching full-ripe stage. Banana hands stored with ethylene absorbent (T_2) recorded the *minimum* PLW on third and sixth day of storage in open condition (Table 8b).

4.2.2. Days to ripening

4.2.2.1. Number of days to half-ripe stage

The treatments differed significantly in the days to half-ripe stage in all the specified storage conditions (Table 9b). At 13°C storage temperature banana hands stored with ethylene absorbent (T_2) recorded the maximum number of days (61.67 days) followed by the control (T_1) (43.00 days) to reach half-ripe stage. Banana hands precooled in iceflakes recorded the lowest number of days (35.33 days).

At 18°C storage temperature, 'Nendran' banana hands stored with ethylene absorbent (T_2) recorded maximum days to half-ripe stage (41.67 days) and all other treatments did not differ significantly.

Under storage at ambient temperature, the banana hands stored with ethylene absorbent (T_2) recorded the maximum number of days (38. 00 days) to half-ripe stage followed by banana hands precooled with ice flakes (T_4) (27.00 days) and the banana hands in control (T_1) and hot water treated ones recorded the least (21.33 and 20.67days respectively).

4.2.2.2. Number of days to full-ripe stage

The number of days taken by a mature of green fruit to become full yellow and edible ripe stage was considered as the days to full-ripe stage.

The treatments showed significant difference in the days to full-ripe stage. The trend was similar to that of the days to the half-ripe stage in all the storage conditions.

At 13°C storage temperature, banana hands stored with ethylene absorbent (T_2) recorded maximum number of days to full-ripe stage (64.33 days) followed by hot water treated banana hands (T_5) (49.00 days) and the minimum days to full-ripe stage was recorded by banana hands precooled in ice flakes (T_4) (42 days).

Among the banana hands stored at 18°C, 'Nendran' banana hands stored with ethylene absorbent (T_2) recorded the maximum days to full-ripe stage (44.67 days). All the other treatments did not differ significantly.

Banana hands stored with ethylene absorbent (T_2) under ambient condition recorded the maximum days (41.33 days) to full ripeness, which was followed by those, precooled with ice flakes (T_4). In the case of banana hands precooled in cold water (T_3) the number of days to reach full-ripe stage was 17.33 days, which was the minimum days recorded to full-ripe stage.

Table 9a. Effect of storage temperature on duration of storability

Treatments	Days of storage		
	Storage temperature		
	13°C	18°C	Ambient
T_1 - Control	42	14	14
T_2 - Storage with ethylene absorbent	49	35	35
T_3 - Storage after precooling with cold water	35	14	14
T_4 - Storage after precooling with iceflakes	35	21	21
T_5 - Storage after hot water treatment	35	14	14

Duration of storability is the period, up to which the fruits showed normal ripening behaviour in open post- storage environment

Table 9b. Effect of storage temperatures on days to ripening of 'Nendran' banana

Treatments	Time taken to reach ripening stage (days)					
	Half-ripe			Full-ripe		
	Storage temperature (°C)			Storage temperature (°C)		
	13°	18°	Ambient	13°	18°	Ambient
T_1	43.00	11.33	21.33	48.00	15.67	23.67
T_2	61.67	41.67	38.00	64.33	44.67	41.33
T_3	39.33	13.00	15.00	44.00	16.33	17.33
T_4	35.33	18.67	27.00	42.00	22.67	30.33
T_5	42.67	17.33	20.67	49.00	20.33	24.33
CD (P=0.05)	6.42	3.48	3.96	6.32	3.32	4.86

4.2.3. Effect of storage temperature on duration of storability

Observations on the days to half-ripe stage revealed information on the number of days 'Nendran' banana could be stored in green condition, without affecting normal ripening behaviour in post-storage. Successful storage is the ability of the fruit to be in green condition and become acceptable in the post-storage stage. The observations on post-storage behaviour of 'Nendran' banana taken at weekly intervals (Table 9a) revealed that 'Nendran' banana hands stored with ethylene absorbent (T_2) could be stored with acceptable qualities for longer period than the other treatments. At 13°C the fruits stored with ethylene absorbent (T_2) were found to be acceptable up to 49 days and those stored at 18°C and ambient temperature, both for 35 days. Storage at 13°C after precooling treatments (T_3 and T_4) and hot water treatment (T_5) recorded the same number of days (35 days) while the control (T_1) recorded 42 days (Plate 11). Extended storage did not show any external symptoms but were not acceptable organoleptically. 'Nendran' banana when precooled with iceflakes (T_4), and stored at 18°C (Plate 10) and in ambient condition showed an improved storage life (21 days) over the control (14 days). Storing at 18°C did not show any additional advantage over storage at ambient temperature.

4.2.4. Shelf-life of 'Nendran' banana stored at different storage conditions.

Shelf-life of a fruit is the number of days a fruit remains in edible or consumable stage (i.e.) from full-ripe stage to prior to the degradative stage (unmarketable stage). The storage condition should aid in increasing the shelf-life of a fruit.

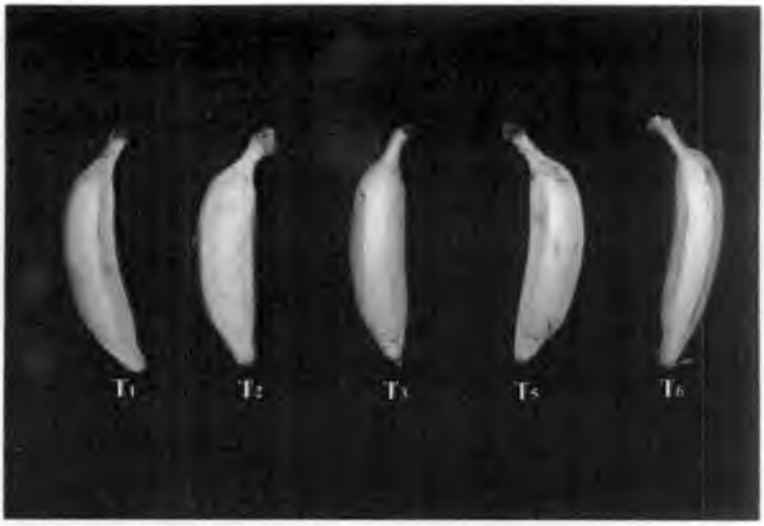

Plate 9. Ripening behaviour of 'Nendran' banana subjected to smoke, ethylene contact, ethrel dipping and stored under open condition

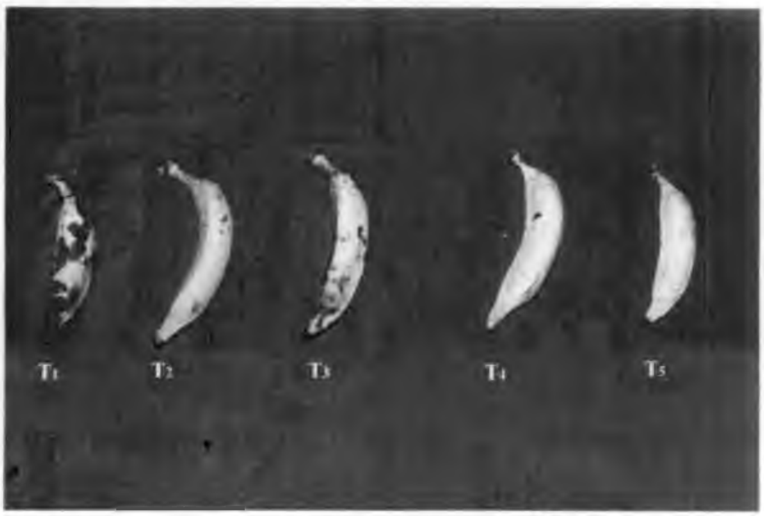

Plate 10. 'Nendran' banana after 14 days of storage at 18°C

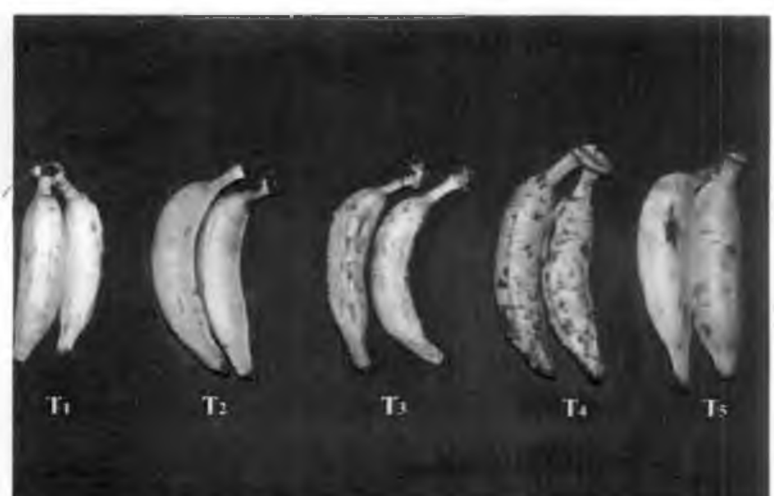

Plate 11. 'Nendran' banana after 35 days of storage at 13°C

Table 10. Effect of treatments at 13°C storage temperature on green-life and shelf-life of 'Nendran' banana in post-storage in open condition

Treatments	Duration of storage at 13°C (days)											
	7		14		21		28		35		42	
	Post-storage		Post-storage		Post-storage		Post-storage		Post-storage		Post-storage	
	Green-life (days)	Shelf-life (days)	Green-life (days)	Shelf-life (days)	Green-life (days)	Shelf-life (days)	Green-life (days)	Shelf-life (days)	Green-life (days)	Shelf-life (days)	Green-life (days)	Shelf-life (days)
T_1	4.33	5.33	4.33	5.33	4.00	6.00	5.33	6.00	4.33	6.00	3.00	6.00
T_2	3.33	4.33	4.00	6.33	4.00	6.33	8.00	6.33	4.33	6.33	7.00	6.00
T_3	3.00	4.00	4.00	4.00	3.67	6.67	3.00	6.33	4.00	6.67	ND	2.33
T_4	3.00	4.33	3.00	6.00	4.00	6.33	3.00	6.67	4.00	7.00	ND	2.33
T_5	3.33	4.00	3.33	6.33	7.33	6.67	10.00	4.33	7.00	6.67	2.67	6.00
CD (P=0.05)	1.15	1.41	1.33	NS	1.33	NS	1.88	1.24	1.76	NS	1.24	2.25

NS – Not significant at 5% level

ND – Not determined due to termination of storage

Table 11. Effect of treatments at 18°C storage temperature on green-life and shelf-life of 'Nendran' banana in post-storage in open condition

Treatments	Duration of storage 18°C (days)					
	7		14		21	
	Post-storage		Post-storage		Post-storage	
	Green-life (days)	Shelf-life (days)	Green-life (days)	Shelf-life (days)	Green-life (days)	Shelf-life (days)
T_1	2.33	5.67	ND	3.33	ND	ND
T_2	7.00	6.00	7.33	5.67	5.00	6.00
T_3	2.33	6.33	1.33	5.33	ND	ND
T_4	6.67	6.33	4.00	6.33	ND	3.00
T_5	2.33	6.67	2.67	6.33	ND	ND
CD (P=0.05)	1.24	NS	1.15	1.05	NS	NS

NS – Not significant at 5% level
ND – Not determined due to termination of storage

Table 12. Effect of treatments at ambient storage temperature on green-life and shelf-life of 'Nendran' banana in post-storage in open condition

Treatments	Duration of storage at ambient temperature (days)					
	7		14		21	
	Post-storage		Post-storage		Post-storage	
	Green-life (days)	Shelf-life (days)	Green-life (days)	Shelf-life (days)	Green-life (days)	Shelf-life (days)
T_1	2.67	4.67	3.67	3.67	ND	ND
T_2	4.00	5.67	4.33	4.67	4.33	5.00
T_3	1.33	3.00	ND	ND	ND	ND
T_4	5.00	6.33	4.00	4.00	4.33	4.67
T_5	3.67	6.33	4.33	3.67	ND	ND
CD (P=0.05)	1.15	0.94	NS	1.15	NS	NS

NS – Not significant at 5% level
ND – Not determined due to termination of storage

Banana hands kept in open condition for post-storage studies recorded a shelf-life ranging from three to six days. The treatments showed an increased shelf-life in open condition after 21, 28 and 35 days of storage at 13°C (Table 10).

'Nendran' hands kept in open condition for post-storage studies at weekly intervals from 18°C storage condition had a shelf life ranging from 3.33 to 6.67 days and the control showed less shelf-life in open condition (Table 11).

The shelf-life of fruits differed significantly in banana hands kept in open condition at weekly intervals from ambient storage condition. Banana hands stored with ethylene absorbent recorded the maximum shelf-life averaging 5.00 days in open condition (Table 12).

4.2.5. Marketability

The marketability of the fruit depends on the shelf-life of the fruit. The fruits with more than 50 per cent of blackening as spots, specks and lesions on skin are considered unmarketable.

Banana fruits kept in open condition after storage at 13°C showed significant difference in marketability (Table 13). The hands proecooled in cold water (T_3) recorded the maximum marketability followed by the hands stored with ethylene absorbent (T_2) and hot water treated (T_5) banana hands up to 35 days of storage at 13°C and storage in open condition on third and sixth days. After 42 days of storage at 13°C, banana hands stored with ethylene absorbent (T_2) in open condition recorded the maximum marketability on third day (93.27%).

The hands kept in open conditions after storing at 18°C did not differ significantly in marketability (Table 14). The banana hands stored with ethylene

Table 13. Effect of treatments at 13°C storage temperature on marketability of 'Nendran' banana in post-storage in open condition

Treatments	Marketability (%)											
	Duration of storage at 13°C (days)											
	7 DAS		14 DAS		21 DAS		28 DAS		35 DAS		42 DAS	
	Duration of storage in open condition (days)		Duration of storage in open condition (days)		Duration of storage in open condition (days)		Duration of storage in open condition (days)		Duration of storage in open condition (days)		Duration of storage in open condition (days)	
	3	6	3	6	3	6	3	6	3	6	3	6
T_1	91.64	79.90	80.99	53.67	87.10	64.13	92.20	72.90	91.83	ND	66.87	ND
T_2	92.50	74.53	84.32	71.88	92.60	75.30	94.12	88.66	94.13	ND	92.21	84.42
T_3	94.46	55.79	86.83	58.55	94.73	47.33	94.63	73.66	92.92	89.45	75.67	ND
T_4	93.39	68.99	82.45	ND	88.56	ND	91.81	73.37	92.61	ND	ND	ND
T_5	92.81	69.58	86.77	76.37	92.67	52.03	92.19	78.30	90.50	ND	ND	ND
CD (P=0.05)	1.80	N.S	2.16	N.S	1.37	N.S	1.36	N.S	5.11	N.S	N.S	ND

DAS – Days after storage

ND – Not determined due to termination of storage

NS – Not significant at 5% level

Table 14. Effect of treatments at 18°C storage temperature on marketability of 'Nendran' bananas in post-storage in open condition

Treatments	Marketability (%)					
	Duration of storage at 18°C					
	7 DAS		14 DAS		21 DAS	
	Duration of storage in open condition (days)		Duration of storage in open condition (days)		Duration of storage in open condition (days)	
	3	6	3	6	3	6
T_1	92.58	75.10	62.97	54.60	ND	ND
T_2	88.60	80.56	90.50	83.00	89.87	83.07
T_3	89.74	75.03	60.47	ND	ND	ND
T_4	89.98	82.27	91.13	68.67	63.10	ND
T_5	93.32	77.47	92.37	76.14	ND	ND
CD (P=0.05)	N.S	N.S	N.S	N.S	N.S	ND

DAS – Days after storage
ND – Not determined due to termination of storage
NS -- Not significant at 5% level

Table 15. Effect of treatments at ambient storage temperature on marketability of 'Nendran' banana during post- storage in open condition

Treatments	Marketability (%)					
	Duration of storage in ambient condition (days)					
	7 DAS		14 DAS		21 DAS	
	Duration of storage in open condition (days)		Duration of storage in open condition (days)		Duration of storage in open condition (days)	
	3	6	3	6	3	6
T_1	89.22	66.19	91.53	76.97	63.80	ND
T_2	91.13	84.71	93.10	87.45	93.47	87.86
T_3	85.50	ND	ND	ND	ND	ND
T_4	94.53	82.00	93.50	74.63	91.00	71.19
T_5	91.11	91.11	91.07	77.63	ND	ND
CD (P=0.05)	N.S	N.S	N.S	N.S	33.09	N.S

DAS – Days after storage
ND – Not determined due to termination of storage
NS – Not significant at 5% level

absorbent (T_2) retained marketability even after 21 days of storage at 18°C. After seven days of storage at 18°C, all the treatments were marketable even after six days in open condition. But after 14 days of storage at 18°C though all the treatments were in marketable condition T_1 and T_3 recorded low marketability (62.97% and 60.47% respectively) on the third day in open condition, and on the sixth day banana hands precooled in cold water (T_3) became unacceptable. After 21 days of storage at 18°C only the hands stored with ethylene absorbent (T_2) and the banana hands precooled in ice flakes (T_4) were marketable on the third day of keeping in open condition.

The hands kept in open conditions after storing at ambient conditions in air-tight container did not differ significantly in marketability (Table 15). The banana hands stored with ethylene absorbent (T_2) and hands precooled with ice flakes (T_4) were marketable even on the sixth day in open condition, after storing in air-tight container for 21 days. The hands precooled in cold water (T_3) became unmarketable after the first week of storage.

4.2.6. Chemical changes during ripening of 'Nendran; banana stored at different storage conditions at different stages of ripening

4.2.6.1. Total soluble solids (T.S.S)

The hands kept in open conditions after storing at 13°C differed significantly in T.S.S on 14th and 42nd days of storage. The maximum T.S.S recorded was 32.00°brix, by banana hands stored with ethylene absorbent (T_2) after storage for 14 days and 30.33°brix after 42 days of storage (Table 16a).

Banana hands kept in open condition for post-storage studies from 18°c differed scientifically in T.S.S on the seventh day and hands stored with ethylene absorbent (T_2) recorded the maximum (30.67°brix) (Table 17a).

T.S.S of the fruits kept in open condition after storing at ambient condition differed significantly only after 21 days of storage and banana hands stored with ethylene absorbent (T_2) recorded the maximum (30.33°brix) (Table 18a).

4.2.6.2. Acidity

The banana hands kept in open condition showed significant difference in acid content after storing at 13°C for 7, 14, 21 and 28 days. The acid content ranged between 0.56 and 0.98. Acid content did not differ significantly on 35 and 42 days of storage at 13°C (Table 16a).

The treatments in post-storage study showed significant difference in acidity after storing in 18°C on seventh day. Control (T_1) and banana hands dipped in hot water (T_5) were on par and recorded an acid content of 0.66% each. The acid content ranged between (0.50 to 0.66%) (Table 17a).

The treatments kept in open conditions after storing in air-tight box at ambient temperature did not show any significant difference in acidity and the acid content ranged from 0.41-0.61% (Table 18a). The acid content of the fruits stored at 13°C was higher compared to the acid content of the fruits stored at 18°C and ambient temperature.

4.2.3.3. Brix:acid ratio

The brix:acid ratio has a specific influence on the taste of the fruit. A higher brix:acid ratio indicates a better sugar: acid blend.

The hands kept in open condition after storing at 13°C, differed significantly in brix:acid ratio after 7, 14, 21, 28 and 35 days. Brix:acid ratio recorded by banana hands treated with hot water (T_5) was higher than the treatments after 7, 14 and 35 days of storage recording 55.13. The brix:acid ratio varied between 32.07 and 55.13 among the treatments after different days of storage at 13°C (Table 16a).

Banana hands stored in open condition after storing at 18°c for seven days differed significantly in brix:acid ratio and banana hands stored after precooling with ice flakes recorded the maximum (57.34). The brix:acid ratio ranged between 44.4 and 57.34 among treatments and in different days of storage (Table 17a).

The hands stored in open condition after 7, 14, 21 and 28 days of storage in the air-tight container at ambient condition did not differ significantly in brix:acid ratio on any day and the brix:acid ratio ranged from 48.03-68.47 among treatments and different days of storage (Table 18a).

4.2.6.4. Total sugars (T.S)

The treatments differed significantly in total sugar content (Table 17b) when kept in open condition after storing in 13°C for 7, 14, 21 and 35 days. Banana hands treated with hot water (T_5) were on par in total sugar content on all the days of sampling. The T.S ranged between 17.06% and 24.17% (Table 16b).

Hands stored in open condition after storing at 18°C differed significantly in total sugars after seven days of storage. The hands precooled in ice flakes (T_4) recorded the maximum (21.70%) total sugars. The total sugars ranged between 16.76% and 21.70% between treatments and on different days of storage (Table 17b).

Fruits stored in open conditions after storing in air-tight container at ambient condition did not differ significantly in total sugar content. The total sugars ranged from 17.58 to 27.59% (Table 18b).

4.2.6.5. Reducing sugar (R.S)

The fruits kept in open conditions after 7, 14, 21, 28 and 35 days of storage at 13°C differed significantly in R.S. content. From fourteenth to thirty-fifth day hands treated with hot water (T_5) was on par with respect to reducing sugar content on seventh day Control (T_1) recorded the maximum valued for R.S. (12.19%) (Table 16b).

Banana hands stored at 18°C and in ambient condition also did not show significant difference in R.S.

4.2.6.6. Starch

The most striking change during ripening is the hydrolysis of starch to simpler sugars.

Banana hands kept in open conditions after 7, 14, 21, 28 days of storage at 13°c differed significantly in starch content. Starch content ranged between 14.57% and 35.05% among treatments and at different duration of storage (Table 16b).

Banana hands stored at 18°C for seven days and then kept in open condition differed significantly in the starch content and hands precooled in cold water (T_3) recorded higher starch content (20.83%) and hot water treated hands recorded the lowest (12.53%) (Table 17b).

Table 16a. Effect of treatments at 13°C storage temperature on acidity, TSS and Brix:acid ratio of 'Nendran' banana kept for post-storage in open condition

Treatments	Duration of storage at 13°C (days)																	
	7			14			21			28			35			42		
	Acidity (%)	TSS (°brix)	B/A	Acidity (%)	TSS (°brix)	B/A	Acidity (%)	TSS (°brix)	B/A	Acidity (%)	TSS (°brix)	B/A	Acidity (%)	TSS (°brix)	B/A	Acidity (%)	TSS (°brix)	B/A
T_1	0.62	30.67	49.92	0.70	30.33	43.20	0.66	29.67	45.24	0.64	30.33	47.68	0.69	30.67	49.92	0.69	28.66	41.52
T_2	0.58	30.67	52.81	0.62	32.00	52.01	0.68	30.00	43.99	0.67	30.33	45.42	0.61	30.67	52.81	0.65	30.33	46.67
T_3	0.98	31.33	32.07	0.56	29.33	52.58	0.59	31.00	52.65	0.77	29.67	38.52	0.63	31.33	32.07	0.73	28.00	38.86
T_4	0.64	30.33	47.39	0.64	30.67	48.17	0.57	29.67	52.20	0.69	29.00	42.03	0.67	30.33	47.39	0.68	28.67	42.29
T_5	0.57	31.33	55.12	0.56	30.33	54.52	0.73	30.00	41.44	0.68	30.33	44.63	0.68	31.33	55.12	0.66	29.33	44.58
CD (P=0.05)	0.56	N.S	5.22	0.06	2.20	5.16	0.09	N.S	7.51	0.06	N.S	4.74	N.S	N.S	5.22	N.S	1.69	N.S

NS – Not significant at 5% level

B/A – Brix : Acid

Table 16b. Effect of treatments at 13°C storage temperature on total sugar, reducing sugar and starch content in 'Nendran' banana kept for post-storage in open condition

Treatments	Duration of storage at 13°C (days)																	
	7			14			21			28			35			42		
	T.S (%)	R.S (%)	Starch (%)	T.S (%)	R.S (%)	Starch (%)	T.S (%)	R.S (%)	Starch (%)	T.S (%)	R.S (%)	Starch (%)	T.S (%)	R.S (%)	Starch (%)	T.S (%)	R.S (%)	Starch (%)
T_1	19.70	12.19	26.68	19.79	5.99	21.47	21.09	6.52	23.55	20.52	5.10	19.28	19.56	5.36	17.46	18.73	6.13	15.42
T_2	22.15	11.22	35.05	17.66	5.41	21.08	18.60	5.70	18.42	19.43	5.86	15.98	19.51	5.58	19.30	19.35	6.93	17.00
T_3	21.38	9.90	19.73	17.06	4.33	17.49	19.39	5.15	19.42	22.52	5.31	17.82	19.59	5.91	20.47	18.96	5.43	26.40
T_4	18.86	7.62	19.31	17.23	3.63	25.17	19.17	5.06	21.87	18.79	5.77	14.57	18.17	5.41	18.20	19.94	5.41	19.50
T_5	22.44	7.78	20.08	19.89	6.34	24.50	22.39	6.37	23.00	25.89	6.37	21.47	24.17	6.31	19.17	19.17	5.32	18.70
CD (P=0.05)	2.14	1.43	9.65	0.98	0.29	2.26	3.15	0.58	3.01	1.97	0.39	3.52	2.24	0.55	NS	NS	NS	6.41

NS – Not significant at 5% level

T.S. – Total sugars

R.S. – Reducing sugars

Table 17a Effect of treatments at 18°C storage temperature on acidity, T.S.S., Brix Acid ratio of 'Nendran' banana kept for post-storage in open condition

Treatments	Duration of storage (days)								
	7			14			21		
	Acidity (%)	TSS (°brix)	B/A	Acidity (%)	TSS (°brix)	B/A	Acidity (%)	TSS (°brix)	B/A
T_1	0.66	29.33	44.45	0.66	29.67	44.95	ND	ND	ND
T_2	0.58	30.67	53.00	0.56	30.33	54.52	0.56	28.67	53.54
T_3	0.63	29.67	47.31	ND	ND	ND	ND	ND	ND
T_4	0.50	28.67	57.34	0.65	31.33	48.24	0.61	29.33	48.69
T_5	0.66	30.33	45.97	0.66	28.67	43.44	ND	ND	ND
CD (P=0.05)	0.06	1.05	4.22	NS	NS	NS	NS	NS	NS

NS – Not significant at 5% level
B/A – Brix : acid
ND – Not determined due to termination of storage

Table 17b Effect of treatments at 18°C storage temperature on total sugars, reducing sugars and starch content of 'Nendran' banana kept for post-storage in open condition

Treatments	Duration of storage (days)								
	7			14			21		
	TS (%)	RS (%)	Starch	TS (%)	RS (%)	Starch	TS (%)	RS (%)	Starch
T_1	17.83	5.79	15.69	18.17	5.05	6.63	ND	ND	ND
T_2	20.13	6.74	15.97	18.00	7.46	5.71	18.07	7.69	15.4
T_3	18.49	6.37	20.83	ND	ND	ND	ND	ND	ND
T_4	21.70	6.60	13.04	18.35	7.46	6.63	17.27	7.24	12.71
T_5	19.34	6.83	12.53	16.76	5.58	6.62	ND	ND	ND
CD (P=0.05)	1.49	NS	3.06	NS	NS	NS	NS	NS	NS

NS – Not significant at 5% level
ND – Not determined due to termination of storage
T.S. – Total sugars
R.S. – Reducing sugars

Table 18a. Effect of treatment at ambient storage temperature on acidity, T.S.S, Brix:acid ratio of 'Nendran' banana kept for post-storage in open condition

Treatments	Duration of storage (days)								
	7			14			21		
	Acidity (%)	T.S.S (°brix)	B/A	Acidity (%)	T.S.S (°brix)	B/A	Acidity (%)	T.S.S (°brix)	B/A
T_1	0.49	28.33	59.66	0.49	29.33	61.76	0.51	28.00	56.08
T_2	0.52	28.67	55.58	0.54	28.67	53.66	0.49	30.33	62.46
T_3	0.42	28.33	68.48	0.45	28.33	63.08	ND	ND	ND
T_4	0.49	29.67	60.65	0.58	29.00	51.39	0.59	29.00	49.21
T_5	0.45	29.33	66.30	0.60	29.00	48.03	0.61	29.33	48.08
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	1.20	NS

NS – Not significant at 5% level
ND – Not determined due to termination of storage
B/A – Brix:acid

Table 18b. Effect of treatments at ambient storage temperature on total sugar, reducing sugar, and starch content in 'Nendran' banana kept for post-storage in open condition

Treatments	Duration of storage (days)								
	7			14			21		
	T.S (%)	R.S (%)	Starch (%)	T.S (%)	R.S (%)	Starch (%)	T.S (%)	R.S (%)	Starch (%)
T_1	17.59	5.05	13.00	27.59	5.22	10.80	18.92	4.92	10.22
T_2	18.59	4.82	9.13	21.26	8.75	10.25	19.41	5.43	10.77
T_3	19.76	5.12	10.46	19.52	5.83	10.85	ND	ND	ND
T_4	19.24	6.34	10.29	19.77	6.92	10.98	20.22	7.15	11.45
T_5	21.13	6.43	9.47	20.29	7.70	8.67	20.03	7.06	6.73
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	2.08

NS – Not significant at 5% level
ND – Not determined due to termination of storage
T.S. – Total sugars
R.S. – Reducing sugars

Fruits stored in air-tight container under ambient conditions and kept in open condition for post-storage differed significantly in starch content only after 21 days of storage in the container and banana hands precooled in ice flakes (T_4) recorded the maximum starch 11.45%. On all other instances the starch content ranged between 6.73% and 13.00%(Table18b).

4.3. Development of packages for retail marketing of banana *Musa* (AAB) 'Nendran'

4.3.1. Physiological loss in weight (PLW) of 'Nendran' bananas in different packages

Physiological loss in weight in the different packages was recorded at every six days interval. Wherever the shelf-life of a particular treatment was terminated prior to a sampling interval, such samples were not available for taking observations subsequently and the respective column in the table was denoted by ND (not determined due to termination of storage). For the rest of the available treatments, analysis was done using "non ortho" option in Mstat C Programme.

Treatments differed significantly with respect to PLW the different packages with an ethylene absorbent at different intervals of observation during the storage period (Table 19a). After six days of storage the hands packed in CFB box (T_1) recorded maximum PLW (11.22%) followed by hands packed in CFB box lined with polyethylene lining (T_2) (2.58). Banana hands packed in polyethylene lined CFB box recorded low PLW than the hands packed in CFB box alone. Banana hands packed in CFB box lined with polyethylene (P.E.) and cut ends applied with Waxol-12% (T_2) recorded low PLW (1.31%) than the hands packed in CFB box with polyethylene lining (2.59%).

Table 19a. Effect of packaging treatments with ethylene absorbent on PLW

Treatments	Physiological loss in weight (PLW) %					
	Duration of storage (days)					
	6	12	18	24	30	36
T_1 – CFB box	11.22	16.72	ND	ND	ND	ND
T_2 – CFB box + P.E. lining	2.59	3.65	4.51	5.83	ND	ND
T_3 – CFB + P.E. lining + Waxol-12% at cut ends	1.31	2.22	4.20	3.74	ND	ND
T_4 – CFB + P.E. lining + (Waxol-12% – Bavistin (1000 ppm)) at cut ends	2.13	2.84	3.56	4.15	ND	ND
T_5 – Ventilated P.E. bag	2.09	3.53	5.39	5.92	ND	ND
T_6 – Unventilated P.E. bag	0.30	0.47	0.84	1.20	2.02	2.69*
T_7 – vacuum pack	0.00	0.00	0.75	1.10	1.58	1.66**
CD (P=0.05)	1.05	0.80	2.53	1.14	0.47	0.62

* - T_6 adjudged as unmarketable on 37^{th} day

** - T_7 adjudged as unmarketable on 47^{th} day

ND – Not determined due to termination of storage

Banana hands packed in ventilated polyethylene bag (T_5) recorded more PLW (2.08%) when compared to the hands packed in unventilated polyethylene (T_6) (0.30%) and vacuum packed (T_7) (0.00%) over a period of six days.

The trend in PLW was same after 12 days of storage. PLW in CFB box packed hands rose to 16.72 per cent, which was significantly more than all other treatments. All the other treatments recorded less cumulative increase.

After 18 days of storage the hands packed in CFB box alone lost their acceptability. Among the other treatments the hands stored in ventilated polyethylene (T_5) recorded maximum PLW% (5.39%) and the hands in vacuum pack recorded the lowest PLW (0.75%).

After 24 days of storage the banana hands packed in CFB with polyethylene lining (T_2) hands packed in ventilated polyethylene bag (T_5) recorded the higher cumulative weight loss of 5.83% and 5.92% respectively. The treatments T_1, T_2, T_3, T_4 and T_5 were ranked unacceptable because of spoilage before 13 days of storage.

Due to rejection of the banana hands stored in T1, T_2, T_3, T_4 and T_5 due to development of unacceptable features, for further estimation of PLW, only two treatments were available. The vacuum packed fruits (T_7) and fruits packed in unventilated polyethylene bag (T_6) which recorded a PLW of 1.57% and 2.02% respectively on the thirtieth day and 2.68% respectively on the thirty sixth day.

The packaging treatments without ethylene absorbent also differed significantly in PLW percentage up to 24 days of storage (Table 19b).

After six days of storage the hands packed in CFB box (T_1) alone recorded the maximum PLW (13.93%) followed by T_5 (unventilated polyethylene bag)

Table 19b. Effect of packaging treatments without ethylene absorbent on PLW

Treatments	Physiological loss in weight (PLW) %				
	Duration of storage (days)				
	6	12	18	24	30
T_1 – CFB box	13.93	19.26	ND	ND	ND
T_2 – CFB box + P.E. lining	2.01	3.16	6.02	7.70	ND
T_3 – CFB + P.E. lining + Waxol 12% at cut ends	1.74	2.58	3.68	4.35	ND
T_4 – CFB + P.E. lining + (Waxol 12% + Bavistin (1000 ppm)) at cut ends	2.47	2.79	4.01	6.50	ND
T_5 – Ventilated P.E. bag	3.17	3.97	6.58	ND	ND
T_6 – Unventilated P.E. bag	0.23	0.33	1.44	1.56	3.20*
T_7 – vacuum pack	0.00	0.13	0.73	0.96	1.22**
CD (P=0.05)	1.56	1.80	0.93	1.01	NS

* - T_6 adjudged as unmarketable on 31^{st} day

** - T_7 adjudged as unmarketable on 43^{rd} day

ND – Not determined due to termination of storage

NS – Not significant at 5% level

3.17%. Banana hands packed in CFB+P.E lining (T_2) and (CFB+P.E lining + cut ends coated with Waxol-12% (T_3), and (CFB+P.E lining + cut ends coated with Waxol-12%+ Bavistin (1000ppm) did not differ significantly in the PLW among them, but recorded a PLW considerably lesser than the hands stored in CFB box (T_1). The hands packed in unventilated polyethylene (T_6) and vacuum pack (T_7) recorded the lowest PLW (0.23% and 0.00% respectively).

After 12 days of storage the trend was similar and hands packed in CFB (T_1) recorded a cumulative PLW of 19.26%, which was significantly more than the other treatments. The cumulative rise in PLW was less after 12 days of storage in all other treatments.

Within 18 days of storage banana packed in CFB box (T_1) became unacceptable due to spoilage. Of the remaining treatments the hands packed in unventilated polyethylene (T_5) recorded maximum PLW (6.58%) by T_3 and T_4 followed by hands in CFB box line with polyethylene (6.02%). PLW of 3.67% and 4.00 respectively which is less then T_2 shows the effectiveness of application of Waxol-12%. Polyethylene bag (T_6) and vacuum pack (T_7) recorded a cumulative PLW of 1.44% and 0.72% respectively. After 24 days of storage also the trend in PLW was similar as that of storage up to 18 days and hands in ventilated polyethylene bag were adjudged unacceptable.

After 30 days of storage only unventilated polyethylene (T_6) and vacuum packed (T_7) were available for recording observations, as T_2, T_3, T_4 and T_5 were adjudged unacceptable because of spoilage by this time span. The cumulative PLW recorded by T_6 and T_7 was 3.20% and1.22% respectively.

4.3.2. Days to ripening

4.3.2a. Number of days to half-ripe stage

The number of days a mature green banana takes to reach hard yellow stage is recorded as the number of days to half-ripe stage. In other words it is the number of days a fruit remains green after harvest.

The packages differed significantly in the days to half-ripe stage when packed with and without an ethylene absorbent. (Table 20). The bananas packed in vacuum pack with ethylene absorbent (T_7) recorded maximum days (42.67 days) to reach the half-ripe stage followed by vacuum pack with out ethylene absorbent (T_7) (38.00 days). Unventilated polyethylene was effective in extending the green-life to 24.67 days, while addition of ethylene absorbent increased it to 31.67 days. Packing in CFB + P.E. lining + cut ends coated with (Waxol-12% + Bavistin(1000 ppm)) with and without ethylene absorbent was on par to CFB + polyethylene lining (T_2) with ethylene absorbent and with ventilated polyethylene bag (T_5) with and without ethylene absorbent. Polyethylene lining was effective in increasing the green-life (12.00 days) over the package in CFB box where the fruits recorded 7.00 days to half-ripe stage (Plate 12).

4.3.2.b. Number of days to full-ripe stage

Placement of an ethylene absorbent in the package influenced the number of days to full-ripe stage. The packages differed significantly in the number of days to full-ripe stage with and without ethylene absorbent. The trend was similar to the number of days to half-ripe stage vacuum packing with ethylene absorbent recorded the maximum days to full-ripe stage (45.33 days) and CFB without ethylene absorbent recorded minimum days (9.67 days).

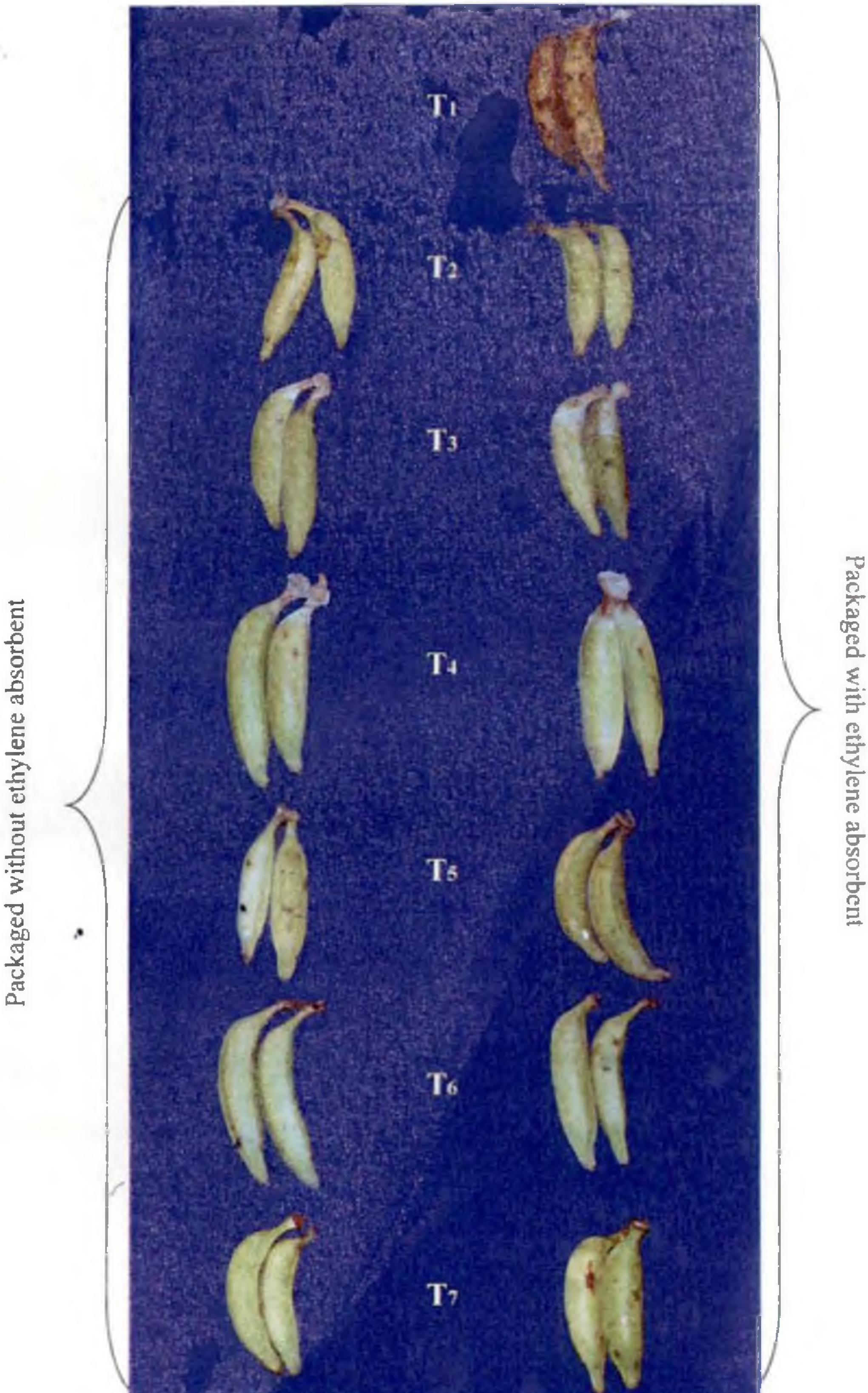

Plate 12. 'Nendran' banana' after 14 days of storage in different packages

Table 20. Effect of packaging treatments on days to ripening

Treatments	Time taken to reach ripening stage (days)					
	Half- ripe			Full-ripe		
	With ethylene absorbent	Without ethylene absorbent	Mean	With ethylene absorbent	Without ethylene absorbent	Mean
T_1 – CFB box	12.33	7.00	9.67	15.00	9.67	12.33
T_2 – CFB box + P.E. lining	16.67	12.00	14.33	19.67	15.33	17.50
T_3 – CFB + P.E. lining + Waxol 12% at cut ends	17.33	17.67	17.50	20.00	20.00	20.00
T_4 – CFB + P.E. lining + (Waxol 12% + Bavistin (1000 ppm)) at cut ends	18.00	18.00	18.00	20.67	20.00	20.33
T_5 – Ventilated P.E. bag	15.67	14.00	14.83	18.67	16.33	17.50
T_6 – Unventilated P.E. bag	31.67	24.67	28.17	34.00	27.00	30.50
T_7 – vacuum pack	42.67	38.00	40.33	45.33	40.33	42.83
Mean	22.05	18.76		24.76	21.24	
CD (P=0.05)	E.A. NS	T 4.38	E.A. × T NS	E.A. 3.15	T 4.31	E.A. × T NS

E.A - Ethylene absorbent
NS – Not significant

Packaging with ethylene absorbent recorded more storage life when compared to the package without ethylene absorbent.

4.3.3. Shelf-life of bananas in different packages

Shelf-life is the number of days from the full-ripe stage to the unmarketable stage. Unmarketability is attributed by blackening of peel as spots, specks and lesions (> 50%). The packages also differed significantly in shelf-life and banana hands in unventilated polyethylene bag (T_5) recorded a longer shelf-life (6.00 days) followed by those packed in CFB box (5.00 days). The hands in vacuum package recorded lowest shelf-life. This is because of the spoilage by rotting of the frits in the package. The reasons for termination of shelf-life of treatments varied from treatment to treatment. The banana hands in CFB box (T_1) was terminated because of severe blackening and the other treatments due to rotting.

The shelf-life was also significantly influenced by the packages without ethylene absorbent and the banana hands in ventilated polyethylene (T_5) recorded maximum shelf-life (6.33) followed by those packaged in CFB box (T_1) (5.33 days). The vacuum packed fruits (T_7) recorded lowest shelf-life (3.67 days) (Table 21).

4.3.4. Marketability of 'Nendran' banana in different packages

Marketability is influenced by PLW and spoilage. The fruits are judged unmarketable when more than 50 per cent of the fruits show blackening as spots, specks or lesions or show rotting (Plate 13,14and15).

Marketability of the different packages supplied with and without ethylene absorbent was recorded on third and sixth day after the fruit has ripened (Table 22).

Plate 13. Unmarketable fruits of 'Nendran' banana packaged in CFB box (20 days after storage)

Plate 14. Unmarketable fruits of 'Nendran' banana packaged in CFB box with polyethylene lining (24 days after storage)

Plate 15. Unmarketable fruits of 'Nendran' banana packaged in

Table 21. Effect of packaging treatments with and without ethylene absorbent on shelf-life of 'Nendran' banana

Treatments	Shelf-life (days)	
	With ethylene absorbent	Without ethylene absorbent
T_1 – CFB box	5.67	5.33
T_2 – CFB box + P.E. lining	4.00	4.33
T_3 – CFB + P.E. lining + Waxol 12% at cut ends	4.67	4.33
T_4 – CFB + P.E. lining + (Waxol 12% + Bavistin (1000 ppm)) at cut ends	4.67	4.67
T_5 – Ventilated P.E. bag	6.00	6.33
T_6 – Unventilated P.E. bag	4.00	4.33
T_7 – vacuum pack	3.33	3.67
CD (P=0.05)	1.21	1.38

Table 22. Effect of packaging treatments with and without ethylene absorbent on marketability percentage

Treatments	Marketability (%)			
	Duration of storage (days)			
	With ethylene absorbent		Without ethylene absorbent	
	3	6	3	6
T_1 – CFB box	77.13	65.76	80.74	66.07
T_2 – CFB box + P.E. lining	95.83	ND	94.25	ND
T_3 – CFB + P.E. lining + Waxol 12% at cut ends	95.80	ND	96.26	ND
T_4 – CFB + P.E. lining + (Waxol 12% + Bavistin (1000 ppm)) at cut ends	96.44	ND	95.99	ND
T_5 – Ventilated P.E. bag	92.21	76.99	95.29	76.99
T_6 – Unventilated P.E. bag	91.78	ND	92.27	ND
T_7 – vacuum pack	66.10	ND	65.53	ND
CD (P=0.05)	1.75	NS	1.75	NS

ND – Not determined due to termination of storage

NS – Not significant at 5% level

Treatments differed significantly in marketability in packages with ethylene absorbent on third day (Table 22). Of the treatments involving CFB box (T_1) recorded the lowest marketability (77.13%) and packages with CFB + P.E lining (T_2), CFB + P.E. lining + cut ends coated in Waxol-12% (T_3) and CFB + P.E. lining + cut ends coated with (Waxol-12% + Bavistin (1000 ppm))(T_4) were on par to T_2 and T_3 and were equally effective in improving the marketability of the fruits.

Ventilated and unventilated P.E bag showed similar effect on marketability on the third day and fruits recorded a marketability of 92.27% and 91.78% respectively. Vacuum packed banana recorded low marketability (66.10%).

On the six day after ripening only hands packaged in CFB (T_1) and ventilated P.E (T_5) recorded marketability (65.76% and 76.99% respectively).

The packages without ethylene absorbent also differed significantly in marketability on the third day (Table 28b). The hands packed in CFB with poly ethylene lining and cut ends coated with Waxol-12% (T_3) recorded maximum marketability (96.26%) followed by package involving CFB + P.E. lining + cut ends coated with (Waxol-12% + Bavistin (1000 ppm)) (T_4) and CFB + P.E. lining (T_2) 95-99 and 94-24% respectively. Vacuum packed banana recorded lowest marketability (65.53%).

On the sixth day the hands packed in CFB (T_1) and in ventilated polyethylene bag (T_5) were marketable (66.06% and 76.99% respectively). Rest of the treatments were adjudged unmarketable before this sampling.

4.3.5. Chemical changes during ripening of 'Nendran' bananas kept in different packages at different stages of ripening

4.3.5.1. Total soluble solids (T.S.S)

T.S.S measured using the refractometer is the general and simple guideline used for assessment of sweetness of fruits. It is regarded that higher the T.S.S sweeter is the fruit.

Packages influenced the T.S.S content differentially at half-ripe and degradative stages both in presence and absence of ethylene absorbent.

At the half-ripe stage, the packages CFB + P.E.lining and cut ends coated with Waxol-12% (T_3), CFB + P.E.lining and ends coated with (Waxol-12% + Bavistin (1000 ppm)) (T_4) both with ethylene absorbent and unventilated P.E. bag (T_6) with and without ethylene absorbent recorded higher T.S.S. The banana hands packed in CFB box recorded the lowest T.S.S irrespective of the presence or absence of ethylene absorbent.

At full-ripe stage the hands packed in CFB box (T_1) recorded a T.S.S (32.67° brix) irrespective of the presence of ethylene absorbent. Banana fruits in vacuum pack without ethylene absorbent recorded the lowest T.S.S (26.33°brix).

At degradative stage bananas packaged in CFB box (T_1) recorded maximum T.S.S (30.00°brix) irrespective of presence of absorbent indicating the fast peel discoloration in the CFB box without pulp degradation. The least T.S.S was recorded by vacuum packed fruits without ethylene absorbent (T_7) (21.33°brix) (Table 23a).

4.3.5.2. Acidity

Titrable acid content of 'Nendran' banana was differentially influenced by the packaging treatments at full-ripe and degradative stages (Table 23a).

At full-ripe stage the banana hands packed in CFB with polyethylene lining and cut ends coated with Waxol-12% (T_3) with and without ethylene absorbent (0.57% and 0.58% respectively) and the banana hands packaged in unventilated polyethylene bag (T_6) with ethylene absorbent (0.58%) recorded the highest acidity followed by CFB + polyethylene lining + cut ends coated with (Waxol-12% + Bavistin(1000 ppm))(T_4) (0.56%) and unventilated polyethylene bag (T_6) (0.54%) both without ethylene absorbent. 'Nendran' kept in CFB box (T_1) recorded lower acidity value (0.435%) when compared to the hands packed in CFB box lined with polyethylene lining. No significant difference in the acid content was recorded between the hands stored in CFB (T_1) (0.435%) and hands stored in ventilated polyethylene bag (T_5) (0.463%). Packaging in vacuum pack reduced the acid content when packed with and without an ethylene absorbent (0.38% and 0.36% respectively).

At the degradative stage trend in acidity was similar to that recorded as in the full-ripe stage T_3 was found to be on par with T_4 and T_6 and T_1 was on par with T_2, T_5 and T_7 at the degradative stage. Packaging in P.E. lining CFB box and application of Waxol-12% to cut ends and packing in unventilated P.E. influenced the acid content of the fruits.

4.3.5.3. Brix : acid ratio

Brix:acid ratio is considered as related to taste of the fruit and a high value indicates a better blend of sugars and acid (Table 23a).

Table 23a. Effect of ethylene absorbent on acidity, T.S.S, and Brix : acid ratio of packaged 'Nendran' banana

Treatments	Stage of ripeness								
	Half-ripe								
	Acidity (%)			TSS (°brix)			Brix : acid ratio		
	With ethylene absorbent	Without ethylene absorbent	Mean	With ethylene absorbent	Without ethylene absorbent	Mean	With ethylene absorbent	Without ethylene absorbent	Mean
T_1	0.44	0.41	0.42	17.33	17.00	17.17	39.70	42.69	41.20
T_2	0.52	0.49	0.50	19.00	21.00	20.00	39.72	42.28	41.00
T_3	0.58	0.63	0.61	24.33	25.00	24.67	41.96	40.41	41.19
T_4	0.65	0.65	0.65	25.67	23.67	24.67	39.74	36.79	38.27
T_5	0.54	0.54	0.54	23.00	24.00	23.50	43.67	47.75	45.71
T_6	0.53	0.62	0.57	25.67	25.33	25.50	49.17	41.03	45.10
T_7	0.54	0.46	0.48	23.33	22.33	22.83	43.43	49.94	46.68
Mean	0.54	0.54	0.54	22.62	22.62	22.62	42.48	42.99	42.73
CD (P=0.05)	E.A. NS	T NS	E.A.×T NS	E.A. NS	T 3.73	E.A.×T 2.64	E.A. NS	T NS	E.A.×T NS

NS – Not significant at 5% level

EA – Ethylene absorbent

Table 23a. Contd...

Treatments	Stage of ripeness								
	Full-ripe								
	Acidity (%)			TSS (°brix)			Brix : acid ratio		
	With ethylene absorbent	Without ethylene absorbent	Mean	With ethylene absorbent	Without ethylene absorbent	Mean	With ethylene absorbent	Without ethylene absorbent	Mean
T_1	0.41	0.46	0.44	32.67	32.67	32.67	74.40	68.47	71.43
T_2	0.51	0.44	0.48	30.33	30.00	30.17	59.84	69.30	64.57
T_3	0.59	0.57	0.58	28.67	27.67	28.17	49.18	49.38	49.28
T_4	0.52	0.56	0.54	29.00	29.33	29.17	56.46	52.52	54.49
T_5	0.41	0.51	0.46	28.33	28.00	28.17	69.98	55.12	62.55
T_6	0.61	0.54	0.58	28.67	28.00	28.33	46.72	51.67	49.20
T_7	0.38	0.36	0.37	27.00	26.33	26.67	73.77	73.29	73.53
Mean	0.49	0.50		28.95	28.57		61.48	59.97	
CD (P=0.05)	E.A. NS	T 0.09	E.A.×T NS	E.A. NS	T 3.40	E.A.×T NS	E.A. NS	T 17.08	E.A.×T NS

NS – Not significant at 5% level
EA – Ethylene absorbent

Table 23a. Contd…

Treatments	Stage of ripeness								
	Degradative stage								
	Acidity (%)			TSS (°brix)			Brix: acid ratio		
	With ethylene absorbent	Without ethylene absorbent	Mean	With ethylene absorbent	Without ethylene absorbent	Mean	With ethylene absorbent	Without ethylene absorbent	Mean
T_1	0.40	0.44	0.42	30.00	30.00	30.00	80.51	74.28	77.40
T_2	0.36	0.44	0.40	28.67	28.67	28.67	80.76	66.36	73.56
T_3	0.53	0.57	0.55	27.33	26.67	27.00	51.25	47.65	49.45
T_4	0.46	0.56	0.51	24.67	23.67	24.17	54.29	42.34	48.32
T_5	0.42	0.39	0.41	26.33	27.67	27.00	64.11	73.81	68.96
T_6	0.51	0.48	0.50	25.33	24.00	24.67	49.91	50.76	5.34
T_7	0.37	0.38	0.37	21.33	22.00	21.67	58.64	58.37	58.51
Mean	0.44	0.47		26.52	26.38		62.78	59.08	
CD (P=0.05)	E.A. NS	T 0.11	E.A.×T 0.07	E.A. NS	T 2.57	E.A.×T 1.82	E.A. NS	T 16.89	E.A.×T NS

NS – Not significant at 5% level
EA – Ethylene absorbent

The treatments differed significantly in brix:acid ratio irrespective of presence of ethylene absorbent, at full ripe and degradative stages.

At full-ripe stage the fruits in CFB box (T_1) with ethylene absorbent (74.39) and vacuum packed (T_7) with and without ethylene absorbent (73.77 and 73.29 respectively) recorded the maximum brix:acid ratio followed by CFB box + polyethylene lining (T_2) without ethylene absorbent (69.30) and ventilated polyethylene bag (T_5) (69.98).

At the degradative stage CFB box (T_1) and CFB box + P.E. lining (T_2) with ethylene absorbent recorded the higher value for brix:acid ratio (80.51 and 80.76 respectively), followed by CFB box (T_1) and ventilated P.E. (T_5) without ethylene absorbent. CFB box + P.E. lining and cut ends coated with Waxol-12% and Bavistin (1000 ppm) (T_4) without ethylene absorbent recorded the lowest (42.34). T_3, T_4 and T_6 had similar brix:acid ratio.

4.3.5.4. Total sugars

The total sugar content of 'Nendran' banana was significantly influenced by packaging treatments at half-ripe and degradative stages (Table 23b).

At half-ripe stage the hands packed in CFB box + polyethylene lining + cut ends coated with (Waxol-12% + Bavistin (1000 ppm)) with ethylene absorbent recorded the maximum total sugars (19.49%) followed by the hands packed in CFB-box + polyethylene lining + cut ends coated with Waxol-12% (T_3) (17.46%). Fruits in CFB box with polyethylene lining without ethylene absorbent recorded the minimum value for total sugars (10.19%).

At the degradative stage CFB box (T_1) and CFB box + P.E. lining (T_2) with and without ethylene absorbent, CFB box + P.E. lining + cut ends coated with Waxol-12% (T_3) with ethylene absorbent (20.16%) and ventilated P.E. without ethylene absorbent (19.35%) recorded high total sugar content and hands packed in unventilated P.E. (T_6) with ethylene absorbent recorded the lowest (13.10%).

The total sugar at the full-ripe stage did not differ significantly and it ranged from 17.11 to 21.24% in the treatments.

4.3.5.5. Reducing sugars

Data on the reducing sugar content was found to vary significantly only at the degradative stage. Banana hands packaged in CFB box P.E. lining (T_2) without ethylene absorbent recorded the maximum reducing sugars (8.83%) followed by banana hands packaged in ventilated polyethylene bag (T_5) (8.34%) and the hands packaged in unventilated polyethylene (T_6) and vacuum pack (T_7) recorded minimum values for reducing sugars (3.96% each). The reducing sugars ranged from 3.90% and 4.67% at half-ripe stage, 4.75 to 8.43% at full-ripe stage and 3.89% and 8.83% at the degradative stage (Table 23b).

4.3.5.6. Starch

The most important biochemical change occurring during ripening is the hydrolysis of starch to simple sugars. The starch content decreases with the progress of ripening process.

The starch content was significantly influenced by different packaging treatments at all the stages of ripening (Table 23b). At half-ripe stage the hands packaged in ventilated P.E. (T_5) and unventilated P.E. (T_6) recorded high starch

Table 23b. Effect of ethylene absorbent on total sugars, reducing sugars and starch content of packaged 'Nendran' banana

Treatments	Stage of ripeness								
	Half-ripe								
	Total sugars (%)			Reducing sugars (%)			Starch content (%)		
	With ethylene absorbent	Without ethylene absorbent	Mean	With ethylene absorbent	Without ethylene absorbent	Mean	With ethylene absorbent	Without ethylene absorbent	Mean
T_1	11.67	16.91	14.29	3.75	4.98	4.36	15.65	10.80	13.23
T_2	10.56	10.20	10.38	3.28	4.52	3.90	20.45	14.85	17.65
T_3	17.46	15.99	16.73	4.27	4.60	4.43	23.70	21.90	22.80
T_4	19.50	15.67	17.58	5.12	4.22	4.67	21.13	26.47	23.80
T_5	11.53	14.21	12.87	3.57	4.31	3.94	28.20	30.33	29.27
T_6	13.32	14.25	13.79	4.21	4.27	4.24	30.97	23.54	27.27
T_7	13.96	11.20	11.58	3.91	4.20	4.06	15.13	12.33	13.73
Mean	13.71	14.06		4.01	4.44		22.18	20.04	
CD (P=0.05)	E.A. NS	T 4.62	E.A.×T NS	E.A. NS	T NS	E.A.×T NS	E.A. NS	T 4.81	E.A.×T 3.39

NS – Not significant at 5% level

EA – Ethylene absorbent

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Table 23b. Contd…

Treatments	Stage of ripeness								
	Full-ripe								
	Total sugars (%)			Reducing sugars (%)			Starch content (%)		
	With ethylene absorbent	Without ethylene absorbent	Mean	With ethylene absorbent	Without ethylene absorbent	Mean	With ethylene absorbent	Without ethylene absorbent	Mean
T_1	19.72	20.11	19.91	6.80	6.94	6.87	6.95	11.48	9.22
T_2	20.40	19.86	20.13	6.82	8.43	7.63	17.01	10.08	13.55
T_3	21.03	18.84	19.94	6.68	6.58	6.63	21.93	13.44	17.69
T_4	19.97	22.00	20.99	6.15	6.22	6.19	12.13	14.63	13.38
T_5	19.90	20.26	20.08	5.59	6.20	5.89	12.57	16.27	14.42
T_6	21.25	20.96	21.10	8.04	7.46	7.75	16.07	15.73	15.90
T_7	17.11	18.33	17.72	4.94	4.75	4.85	8.68	8.17	8.42
Mean	19.91	20.05		6.43	6.65		13.62	12.83	
CD (P=0.05)	E.A. NS	T NS	E.A.×T NS	E.A. NS	T NS	E.A.×T NS	E.A. NS	T 2.96	E.A.×T 2.09

NS – Not significant at 5% level
EA – Ethylene absorbent

Table 23b. Contd...

Treatments	Stage of ripeness								
	Degradative stage								
	Total sugars (%)			Reducing sugars (%)			Starch content (%)		
	With ethylene absorbent	Without ethylene absorbent	Mean	With ethylene absorbent	Without ethylene absorbent	Mean	With ethylene absorbent	Without ethylene absorbent	Mean
T_1	19.63	19.79	19.71	7.97	6.34	7.16	4.90	6.13	5.52
T_2	18.77	20.62	19.69	6.64	8.83	7.74	4.63	7.00	6.12
T_3	20.16	18.03	19.10	6.75	4.89	5.82	6.37	5.12	5.74
T_4	17.59	13.73	15.66	4.27	4.64	4.45	7.08	7.83	7.46
T_5	17.34	19.35	18.35	4.69	8.34	6.52	6.32	5.00	5.66
T_6	13.10	14.28	13.69	3.89	3.97	3.93	5.58	7.42	6.50
T_7	15.22	14.53	14.88	4.52	3.96	4.24	2.72	4.37	3.54
Mean	17.40	17.19		5.54	5.85		5.37	6.21	
CD (P=0.05)	E.A. NS	T 3.01	E.A.×T 2.13	E.A. NS	T 3.36	E.A.×T 2.37	E.A. 1.45	T 1.92	E.A.×T 1.36

NS – Not significant at 5% level

EA – Ethylene absorbent

content (29.26% and 27.26% respectively) followed by the hands stored in CFB box with polyethylene lining with cut ends coated with Waxol-12% (T_3) and the hands stored in CFB box with polyethylene lining with cut ends coated with Waxol-12% + Bavistin (T_4) (22.8% and 23.8% respectively). The hands of fruits packed in CFB box lined with polyethylene were on par in starch content with fruits packed in CFB box.

At full-ripe stage fruits in CFB box + polyethylene lining and cut ends coated with Waxol-12% recorded the maximum starch content (17.68%) followed by unventilated P.E. pack (T_6) (15.9%) and ventilated P.E. pack (T_5) (14.42%). T_2 and T_1 were on par with T_4 and T_7 respectively and T_7 recorded the lowest starch content. Though peel colour indicated full-ripe condition the fruits packed in polyethylene recorded high starch content compared to the fruits kept in CFB box indicating a slow rate of starch hydrolysis in fruits packaged in polyethylene covers.

At the degradative stage, bananas in CFB box + polyethylene lining + cut ends coated with (Waxol-12% + Bavistin (1000 ppm)) recorded the maximum starch percentage (7.45%) followed by fruits packaged in CFB box with polyethylene lining (T_2) (6.12%) and unventilated polyethylene (T_6) (6.5%). The treatments T_1, T_3 and T_5 were on par. T_7 recorded the lowest starch content (3.54%).

Presence of polythene as packaged enhanced the peel colour changes to yellow but the changes in pulp were not proportional to the changes in the peel.

4.3.6. Organoleptic evaluation of the various packaging treatments

Organoleptic evaluation is used to describe the sensory impressions associated with the fruit at the time of consumption.

Table 24. Effect of packaging treatments with and without ethylene absorbent on organoleptic qualities of 'Nendran' banana

Treatments	Organoleptic score							
	With ethylene absorbent				Without ethylene absorbent			
	App	Flv	Taste	O.A	App	Flv	Taste	O.A
T_1	6.2	6.7	6.4	6.1	6.0	5.9	6.6	5.7
T_2	1.1	7.4	7.7	6.2	5.7	6.7	6.7	5.9
T_3	6.3	7.5	6.4	6.8	6.5	6.8	6.3	6.7
T_4	6.3	7.8	7.6	6.9	6.2	6.7	6.6	6.8
T_5	5.9	7.6	6.4	6.1	5.9	7.3	6.8	6.5
T_6	5.0	6.7	5.6	5.9	4.6	5.2	5.6	5.7
T_7	3.8	6.4	5.3	5.0	5.2	5.4	5.6	4.5
Kruskal wallis 'H' value	5.53^{NS}	10.05^{NS}	14.19^{NS}	33.15^{*}	2.75^{NS}	5.24^{NS}	5.33^{NS}	4.44^{NS}

* significant at 5% level

NS – Not significant at 5% level

App – Appearance

Flv – Flavour

OA – Over all acceptability

Legend of score
0 – 2 Poor
3 – 5 Satisfactory
6 – 8 Good
9 – 10 Excellent

The packages did not influence the appearance, flavour, and taste of 'Nendran' banana but showed significant difference in overall acceptability in packages containing ethylene absorbent. (Table 24).

'Nendran' banana packaged in CFB box + P.E. lining + cut ends coated with (Waxol-12% + Bavistin (1000 ppm)) (T_4) recorded maximum score (6.9) followed by fruits packaged in CFB box + P.E. lining + cut ends coated with Waxol-12% (6.8). Vacuum packed fruits recorded low score (5.0) for overall acceptability.

'Nendran' banana packed in CFB box lined with P.E. and cut ends coated with Waxol-12% and those in CFB box with P.E. lining and cut ends coated with (Waxol-12% and Bavistin (1000 ppm)) recorded high acceptance organoleptically. So packing of 'Nendran' in CBF box + P.E. lining with cut ends coated with Waxol-12% could be an ideal package among the packages in CFB box.

4.4. Development of grading system for banana *Musa* (AAB) 'Nendran'

In the increasing trend of supermarket shopping where both quality and appeal of the product are given more importance, the customer is ready to pay a better price for the quality produce. 'Nendran' banana, though sold on the basis of weight, the consumer will be ready to pay a higher price for the hands with good quality. Hence, development of a grading system will help both farmer and consumer to get better return for their input respectively.

The mean values of the various physical parameters considered for the study viz. number of fingers/hands, length of finger, girth of finger, curvature of finger, weight of finger and weight of hand, and the mean score for general appearance of different hands of a bunch are give in Table 25.

The table shows that the number of fingers ranged between 8 to10, in different hands. Length of fingers ranged between 20.0 to 23.5 cm, girth of fingers ranged between 10.5 to13.0 cm, curvature of fingers ranged between 1.2 to1.4, weight of hand ranged between 120 to 175g, in different hands of a bunch. This shows variation in these physical parameters between different hands of a bunch. So, hands with similar physical parameters could be grouped and a grading system could be proposed for marketing of 'Nendran' banana with hands as units.

The scores for general appearance by visual assessment showed high rating for hands with more length, diameter and weight. But the opposite was true for ratings of curvature. The fingers with less curvature are preferred over that with more curvature and the present study also proved the same. Curvature of the fruit is an important character in packaging. Curvature was found to influence the packaging density.

Paired 't' test of the scores for general appearance has revealed that different hands could be grouped into four grades. The test showed that first hand and second hand with average scores of 6.49 and 6.78 respectively did not differ significantly in score. But a significant difference was found in the scores of the first and second hands with those of other hands. So it was possible to group the first and second hands, and the hands with the physical parameters within the range of measurement of these two hands are graded as 'A'. (Table 26)(Plate16).

The third hand recorded an average score of 6.15. It differed significantly from the scores of all the other hands, so the fruits with physical parameters with in the range of third hand measurements are graded as 'B'.

The scores of fourth and fifth hands (5.87 and 5.53 respectively) did not differ among themselves, but differed from all the other hands. So the hands with

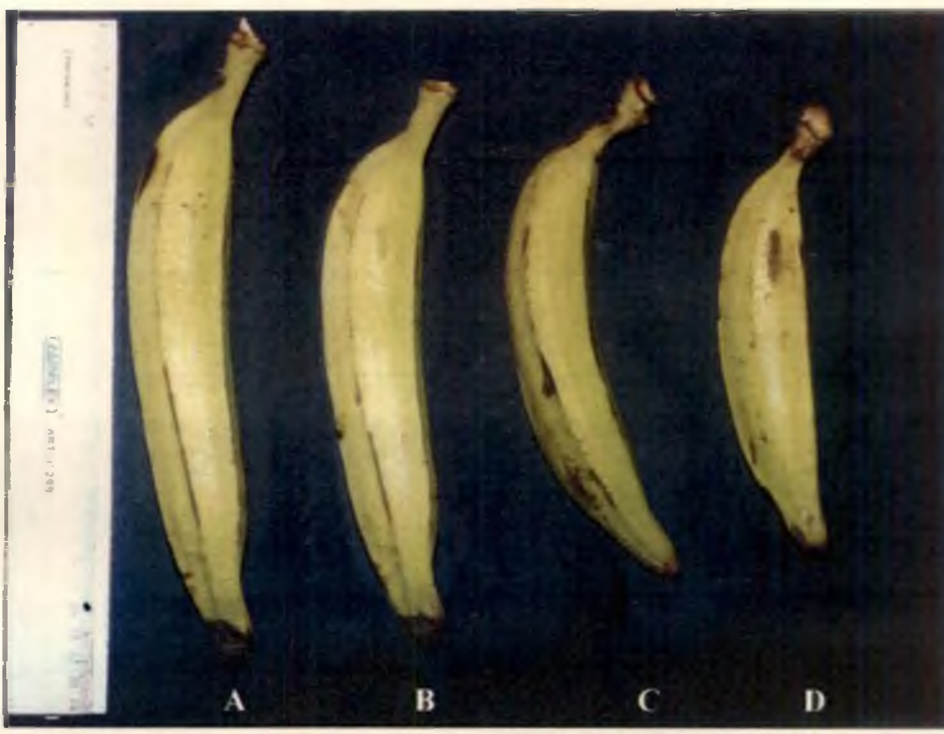


Plate 16. Different grades of 'Nendran' banana

Table 25. Variation of physical parameters between the different hands of 'Nendran' banana in a bunch

Hand No.	No. of fingers/ hand	Length of fingers (cm)	Girth of fingers (cm)	Curvature of fingers (OL/IL)	Weight of hand (kg)	Weight of fingers (g)	General appearance (score)
1	8.56	23.55	12.61	1.21	1.58	175.46	6.49
2	9.08	23.17	12.54	1.21	1.51	161.47	6.78
3	8.74	21.86	12.12	1.27	1.32	144.55	6.15
4	8.98	21.84	12.03	1.28	1.25	135.06	5.87
5	9.19	20.53	11.66	1.31	1.22	130.09	5.53
6	9.67	20.15	11.09	1.38	1.26	113.01	5.26
7	9.00	20.00	10.75	1.41	1.18	118.00	5.31

OL – Outside length
IL – Inside length
Legend of score
0 – 2 Poor
3 – 5 Satisfactory
6 – 8 Good
9 – 10 Excellent

(Values given in the table are mean values of observations taken from 50 bunches of 'Nendran' banana)

Table 26. Suggested grade specifications of 'Nendran' banana with 'hands' as a unit

Grade suggested	Specifications				
	Length of finger (cm)	Girth of finger (cm)	Curvature of finger OL\IL	Weight of hand (g)	Weight of finger (g)
Grade-A	>23.00	12.5 – 13.0	1.2 – 1.25	1500 – 1600	160 – 175
Grade B	22 – 23.0	12.0 – 12.5	1.2 – 1.25	1250 – 1500	140 – 160
Grade C	20.5 – 22.0	11.5 – 12.00	1.25 – 1.3	1200 – 1250	130 – 140
Grade D	< 20.5	10.5 – 11.5	1.3 – 1.4	1000 – 1200	110 – 130

their physical parameters within the range of fourth and fifth hand measurements are grouped and are graded as 'C'.

The scores of hands after fifth hand, though differed significantly among them, had only satisfactory scores. Hence, the hands with physical parameters within the range below fifth hand measurements are grouped and are graded as 'D'.

The specifications for each grade according to the above grading are as follows:

Grade A – Hands of finger length more than 23.00 cm, girth range of 12.5 to13.0 cm, curvature of 1.2 to1.25, hand weight of 1500 to1600g and finger weight between 160 to175 g.

Grade B – Hands of finger length between 22.0 to 23.0 cm, girth range of 12.0 to12.5 cm, curvature of 1.2 to1.25 hand weight between 1250 to1500 g and finger weight between 140 to160 g.

Grad C – Hands of finger length between 20.5to22.0 cm, girth range of 11.5 to 12.0 cm, curvature of 1.25 to1.3 , hand weight of 1200 to1250 g and finger weight of 130 to140 g.

Grade D - Hands of finger length less than 20.5, girth range of 10.5to11.5 cm, curvature of 1.3to1.4 ., hand weight of 1000 to1200 g and finger weight of 110-130 g.

The suggested grades and their specifications are given in Table 26.

Discussion

DISCUSSION

Banana is a fruit, with climacteric pattern of ripening behaviour and therefore, perishable after harvest .Its high metabolic rate and ethylene production hasten the ripening and senescence stages. As fruits continue its physiological processes even after harvest, efforts to extend its shelf-life will be successful only if the metabolic rate is brought to a low pace, with consequent minimal loss of nutrients (Burton, 1982). So efforts to increase the green-life of banana should necessarily focus on decreasing the metabolic rate and reducing the synthesis of ethylene in harvested tissues.

Different methods and approaches for extension of shelf-life in fruits have been tried. One of the attempts is by storing the fruits, just above the chilling temperature. In chilling sensitive commodities optimum storage temperature is fixed slightly above the chilling sensitivity level. Another approach to increase the green-life of banana is by packing in polyethylene bag, which had been suggested by many scientists (Scott *et al.,* 1971, Fuchs and Gorodriski, 1971, De *et al.,* 1988 and Ferris, 1997).

The fruits of banana are harvested unripe and are inedible at this stage, the eating quality of bananas develop during subsequent postharvest ripening. A proper ripening treatment can make the fruit edible in a shorter period of time and there fore, has considerable commercial relevance.

To evaluate the behaviour of 'Nendran' banana in the above mentioned situations, the present study titled "Postharvest handling and packaging systems for 'Nendran' banana", was taken up. Also an attempt was made to suggest some guideline for grading 'Nendran' banana with a view to ultimately help farmer get the due price to his produce.

The study was conducted under four experiments and results of the four experiments are discussed in the following pages.

5.1. Experiment I

5.1.1. Studies on ripening of banana *Musa* (AAB) 'Nendran'

'Nendran' banana bunches are brought to market in mature green stage. If kept for storage under open conditions the fruits take longer time to ripe and in the meantime lose their freshness. Also the pattern of ripening is uneven and storage life reduced. In this experiment an attempt was made to identify a quick ripening method, which is feasible and better in terms of ease of adoption, less labour intensive and at the same time maintains quality of the fruit.

Forcing bananas to be in contact with smoke to ripen the fruit is an age old farmers practice. On a commercial scale bananas are still artificially ripened by a smoke filling treatment of the ripening room. The modern methods of artificial ripening employ the use of ethylene releasing chemicals. Ethrel (Ethephon) is one such proprietary compound. Reports on use of ethrel as a ripening agent in banana has been given by many workers (Rao *et al.*, 1971, El-Banna, 1976, Shaaban, 1988, Gosh, 1997). In the present study both these agents were evaluated for assessing their efficiency in inducing ripening in 'Nendran' banana.

5.1.2. Effect of postharvest treatments on PLW

Loss of water from the fruit is a result of process like transpiration and respiration. Increased rate of ripening increases the rate of respiration and there by transpiration. Banana hands stored in smoke filled chamber for 24 hours recorded more PLW among the smoke treatments. Smoke is a mixture of hot air and other hydrocarbons. Therefore, hot air can accommodate more water vapour thus leading to excessive transpiration during storage. The accelerated ripening process is due to the higher temperature prevailing in the air-tight ripening chamber would have contributed to increased loss of water from bananas.

Banana hands dipped in ethrel (1000 ppm) solution recorded high PLW among ethrel treatments which could be attributed to the accelerated ripening and storage in open condition in ambient temperature resulting in a heat build up in the fruits. More than 50 per cent decrease in weight of banana fruits when the fruit reached full-ripe condition was reported by Sen *et al.* (1982).

5.1.3. Effect of postharvest treatments on days to ripening

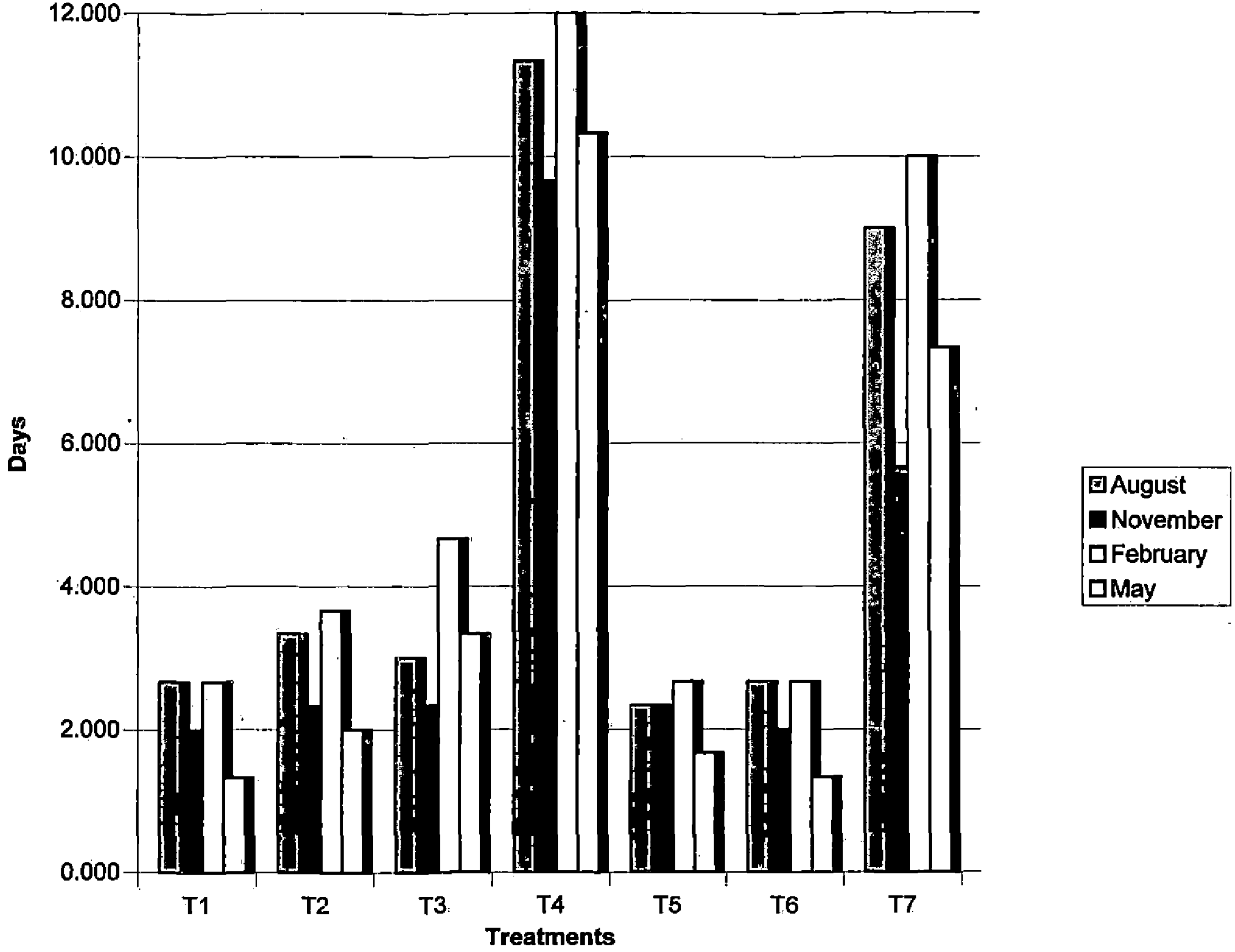
Banana being a climacteric fruit autocatalysis of ethylene production is a common feature of ripening fruits in which a massive increase in ethylene production is triggered by exposure to ethylene above a thresh hold level (Yang and Hoffman,1984). The unsaturated hydrocarbons in smoke and ethylene released from ethrel induce the fruit to ripen quickly by accelerating the biochemical changes leading to ripening. The smoke treatments and ethrel treatments did not differ significantly in the number of days to reach half-ripe stage and recorded two to three days in different seasons, when the banana hands kept in open condition (control) recorded seven to ten days. A two to three fold increase in respiratory rate of ethylene production compared to control, in ethylene treated fruits was reported by Acedo and Bautista, 1993) and therefore, the present finding agree with this view.

As all the smoke filling treatments with different retention durations (24,48,72 hours) showed no significant difference in the days to reach half-ripe stage, a 24 hr retention in smoke chamber could be considered sufficient to initiate ripening in 'Nendran' banana (Fig 1). Enhanced ripening due to smoke contact was also reported by Agnihotri and Ram (1971). Ripening of 'Nendran' banana in three days in common smoke house was also reported by Aravindakshan (1981).

Ripening behaviour of banana hands dipped in ethrel (1000ppm) solution and banana hands kept in ethylene vapour filled chamber did not differ significantly in days to reach half-ripe stage (Fig 1). The present experiment showed that a contact time in a dip for five minutes in 1000ppm solution is sufficient to initiate ripening in 'Nendran' banana. El-Banna (1976) has reported no variance due to time of dipping and, ripening of Gros michel banana in four days when dipped in 1000ppm ethrel solution. Robusta hands dipped in 1000ppm ethephon for two minutes gave best results (Kohli and Reddy, 1983). Enhanced ripening in direct treatment with ethephon 1000ppm was reported by (Shaaban, 1988). Spraying or dipping fruits in 1000ppm ethephon enhanced ripening process (Gosh *et al.,* 1997). Since in the present study the dipping time was five minutes, there in further scope to investigate the effect of ethrel solution with shorter contact time or even a spray of the ethrel solution.

'Nendran' banana hands that were kept in open condition after keeping for 48 hrs in the ethylene vapour filled chamber showed accelerated ripening. Similar report of banana ripened in 48 hrs in air-tight chamber with ethrel solution of 5000ppm with 5g sodium hydroxide pellets in beaker was reported by Rao *et al.* (1971). Gobardhan (1994) reported that Dwarf Cavendish banana fruits ripened in five to six days to reach the edible stage when placed in open condition after keeping in air-tight cabinet containing a beaker of 250ppm ethrel and 2% Sodium hydroxide for 24 hrs and fruits dipped in 250ppm ethrel took 7-8 days to reach the same stage.

Fig.1. Effect of postharvest treatments on days to ripening of 'Nendran' banana in different seasons



'Nendran' banana could be successfully ripened in an ethylene vapour filled chamber in 48 hrs. This could be done at the farmers and traders level, as it does not involve any sophisticated equipment and expertise. It also reduces the cost of labour compared to the ethrel dip method.

5.1.4. Effect of postharvest treatments on marketability and shelf-life

Smoke treated and ethrel treated fruits reached full-ripe stage much ahead of other treatments. However, with respect to marketability, it was observed that smoke treatment and ethrel treatments showed a shorter span of marketability of three days. Smoke treatment for 24 hrs recorded marketability as low as 70.17% on the third day of storage. The reduced marketability could be attributed to lesions on the peel to high evaporation loss and also spoilage. The smoke treated fruits were rendered unmarketable because of black speaks which led to the reduced shelf-life of the fruits. The high rates of respiration accelerated the breakdown of sugars of the fruit. Change of water insoluble pectin to soluble form is the change associated with ripening of fruits. This would have accelerated movement of water from pulp to peel and then to the outside environment in accordance with the vapour gradient (Wills *et al.*, 1989). Report on black specks and other skin blemishes in smoke treated fruits was given by Shenmugavelu *et al.* (1992) and Aravindakshan (1981). A marketability of 12 per cent of smoke treated banana fruits was given by Agnihotri and Ram (1971).

'Nendran' banana ripened in ethylene vapour chamber recorded more marketable percentage than the fruits dipped in 1000ppm ethrel solution. The reduced marketability of ethrel dipped banana could be because of the accelerated ripening resulting in high PLW and spoilage thus reducing shelf-life of the fruits. Report of reduction in marketability of Gros-michel banana dipped in ethephon solution was also given by El-Banna (1976).

Thus ethylene vapour filled chamber treatment could be recommended as an effective tool for ripening 'Nendran' bananas. To extend the shelf-life of 'Nendran' bananas ripened with ethrel treatments, further investigations may be required in lines of reducing concentration of ethrel, storage of ripened banana in low temperature environment etc.

Reducing concentration of ethrel could be a more practical solution, as low concentration of ethylene is sufficient for inducing ripening, as this would also reduce the cost of treatment. Storage of ripened banana in low temperature would also reduce the rate of degradative changes, but this would involve an additional cost of storage.

5.1.5. Effect of Postharvest treatments on biochemical constituents

During ripening of banana fruits, the softening of tissue takes place, starch is degraded to sugars in both pulp and peel, cell walls loose their rupture strength slowly, turns light green and then to yellow with chlorophyll breakdown. During colour change the pulp becomes softer and sweeter as the ratio of sugars to starch increases and characteristic aroma is produced. Eventually the peel becomes spotted brown and then completely brown (Robinson, 1996).

The increase in sugars due to starch hydrolysis in turn increases the T.S.S content. The high T.S.S 29.33 to 30.67° brix recorded by bananas dipped in ethrel (1000ppm) solution might be due to rapid hydrolysis of starch to sugars due to increased enzymatic action during accelerated ripening. Similar opinion on increase in T.S.S content with increase in sugars was given by Emerald and Narayana (1999). Increase in T.S.S in ethylene treated Cavendish banana was reported by

Agravate *et al.* (1991). Increase in T.S.S of C.V.Silk treated with ethephon was reported by Sanchez *et al.* (1996).

5.1.6. Effect of postharvest treatments on organoleptic qualities

Smoke contact treatments recorded low scores for all the organoleptic qualities. The poor acceptance might be due to the smoky flavour and presence of black speaks on the fruit. Poor eating quality and flavour of smoked fruits was also reported by Agnihotri and Ram (1971) and Shenmugavelu and Selvaraj (1988).

Ethrel treatments recorded maximum score for over all acceptability. This is in agreement with the findings of Rao *et al.* (1971) in Robusta bunches kept in a ripening chamber with ethrel solution of 500ppm with 5g of sodium hydroxide pellets kept in a beaker showed better organoleptic qualities for taste, aroma and flavour. Rapid reduction in total chlorophyll content in peel of banana fruits, treated with ethephon was observed by Srinivasan *et al.* (1974). This might be the reason for the attractive yellow colour developed by ethrel treatments. The high T.S.S in fruits due to increase in sugars during ripening due to starch hydrolysis would have contributed to the good taste and flavour. High levels of ethephon (500 and 1000ppm) gained high rates of T.S.S. And treated fruits attained their sweet palatable flavour and eating quality in four days (El-Banna, 1976). Thus ethylene treated 'Nendran' banana come to marketable stage early with increased market acceptability. This finding has great economic relevance in the markets of 'Nendran' banana in Kerala.

Effects of treatments were not influenced by seasons. This is in agreement with the findings of Marin *et al.* (1996) who reported identical ethylene production and ripening rates in June, September, February and March indicating little influence of season on physiology of banana ripening.

Though the present study showed smoke and ethrel as effective ripening agents. Smoke filling as a treatment has many disadvantages compared to ethrel treatments. As the exact concentration of ethylene in the smoke is not known, in order to get good ripening. Excessive quantity of smoke introduced to the ripening chamber produces an ultimate smoke flavour, which is persistent for a few days. Also heat of the smoke cause more transpiration losses and enzymatic browning in the fruits. Smoke chambers are attached to shops of wholesaler in busy market areas. Smoke filling is usually done in the evening just before the closing of the shop. The fire in the smoke blower will persist for many hours in the night after closing of the shop. Unless proper care is taken there is a great threat, which is not appreciated by shopkeepers or the authorities of the local bodies.

Smoke filling treatment is also labour intensive which increases the cost of marketing and it also causes inconvenience while handling like irritation to eye etc.

In contrast to smoke filling treatment, ethrel treatments, could be conveniently used, without any health hazards. Of the ethrel treatments, dipping of banana hands in ethrel solution of 1000ppm would cost Rs.4.31/hand of 'Nendran' fruits. For dipping one hand of 'Nendran' banana 3 l of ethrel solution would be required. 7.5 ml of 40% etherel would be sufficient to prepare 3 l of 1000ppm solution.

Ripening 'Nendran' banana in ethylene filled chamber of 1 cum would cost about 12 Rs for 320 Kg. 1cum of ripening chamber would accommodate about 320 Kg of 'Nendran' banana (320-350 Kg of banana can be accommodated in 1cum (NHB,2004)). The quantity of ethrel required to ripen banana in 1 cum ripening chamber would be 300 ml of 5000ppm solution .To prepare this solution 1.3 ml of 40% ethrel solution is added to 300 ml of water. To release ethylene from ethereal solution about 30g of NaOH would be required for that quantity of ethrel solution. The cost of 40% ethrel solution is Rs 230/100 ml and Sodium hydroxide is Rs 280/1000 g. As ethrel releases ethylene in alkaline medium, the cost of this treatment could be further reduced by use of cheaper material like sodium carbonate or biologicals like exudates of pseudo stem of banana.

Thus considering the costs and benefits it could be concluded that treatment of 'Nendran' banana in an ethylene vapour chamber would be an easy, economic and safe method.

5.2. Experiment II

5.2.1. Development of suitable technique for extension of shelf-life of banana *Musa* (AAB) 'Nendran'.

Banana being a climacteric fruit it is highly perishable once ripening has initiated. Its shelf-life is short at ambient condition of storage and there is a need to develop a suitable method for extending shelf-life. Low temperature storage is one of the commercially adopted ways extending shelf-life of perishable commodities.

Banana is susceptible to chilling injury when stored at temperatures below 12°C and temperatures of 18-20°c with high humidity is considered as favourable temperature to initiate ripening in banana (Salunkhe and Desai, 1984).

Greater the reduction in respiration and general metabolism, longer is the storage life that is, time that produce can be held in an acceptable condition after harvest. Low-temperature storage not only decreases the production of ethylene, but also the rate of response of the fruit tissue to applied ethylene. Banana is susceptible to chilling injury at temperatures below 12.8°C (Pentastico *et al.*, 1975). Chilling injured fruits show slow colour development during ripening. Chilling also affects the ripening physiology by delaying the climacteric rise and producing multiple peaks of respiration (Murata, 1969). Time of exposure as well as the temperature, determine the damage by low temperature. In the present study efforts were made to identify an ideal storage temperature for 'Nendran' to extend its green-life without deterioration of quality.

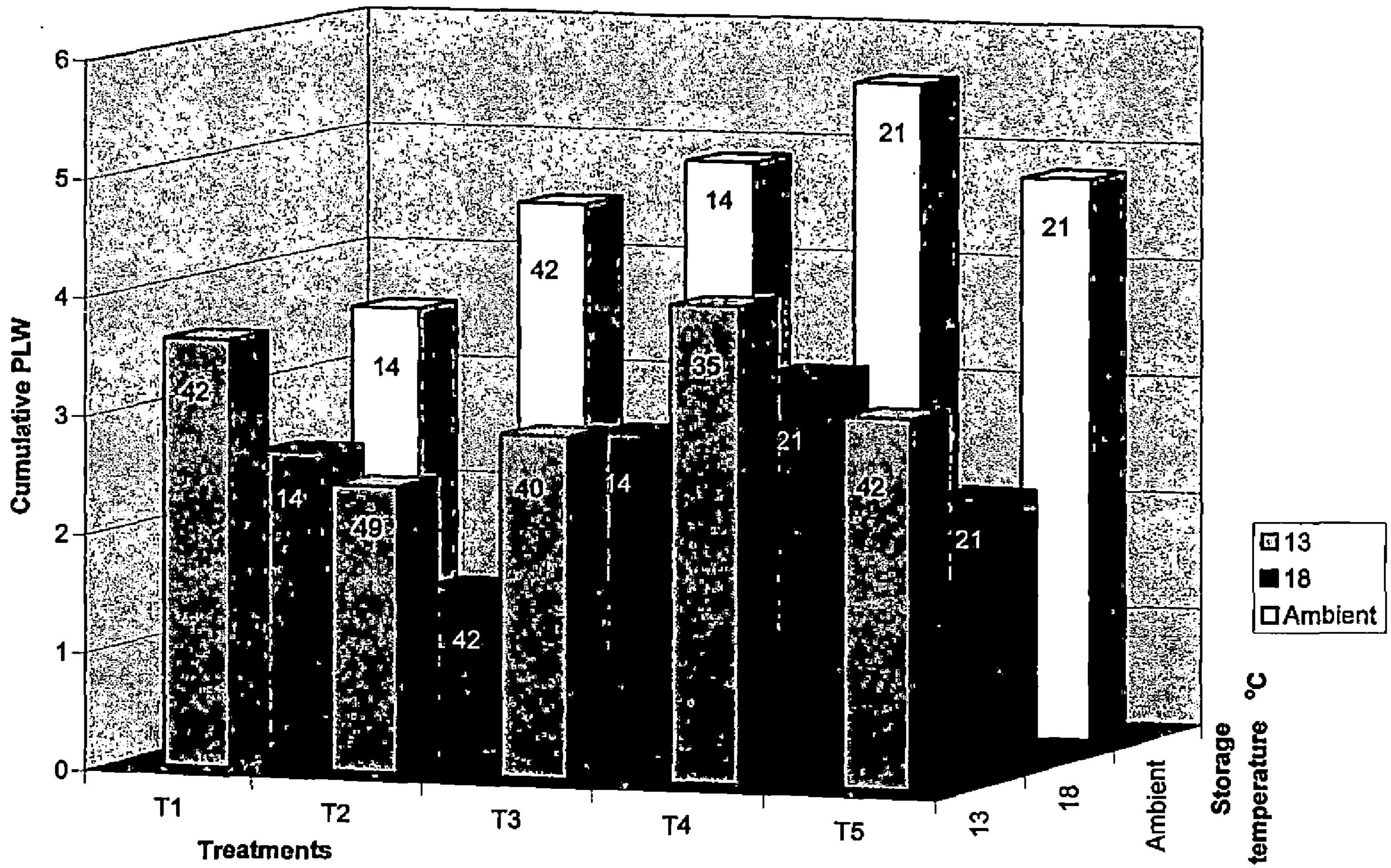
5.2.2. Effect of storage temperatures on PLW

Loss of water after harvest is known to affect the storage and ripening of bananas and the storage life is less under low humidity conditions (Marriott *et al.*, 1979). Methods of controlling the rate of water loss from the produce primarily involve lowering the capacity of the surrounding air to hold additional water by lowering the temperature or raising humidity that is, by reducing the vapour pressure difference between the produce and the air, or by providing a barrier to water loss (Wills *et al.*, 1989).

In the present study the treatments differed significantly in PLW of 'Nendran' banana kept for storage and subsequent ripening. The hands stored with ethylene absorbent, recorded minimum PLW in all the three storage conditions (Fig 2). This reduction in PLW might be due to reduced respiration rate. Ethylene absorbent would have helped the banana hands to remain in the pre-climacteric phase for a longer period of time, which ultimately helped to record a lower value for PLW. The decrease in temperature also reduced the rate of respiration by diminishing enzymatic activities (Prasad and Singh, 1996). Storage at 13°C considerably suppressed respiration rate, ethylene production and ripening (Lebibet *et al.*, 1995).

Precooling is done to reduce field heat of the harvested produce. Harden burg (1971) had reported that precooling when supplemented with low temperature

Fig. 2. Cumulative PLW of 'Nendran' banana under different storage temperatures



Note: Storage Life in days is marked at the top end of the bars storage gave longer shelf-life. Precooling reduces the rate of respiration and transpiration in the harvested produce by reducing the temperature of the harvested commodity.

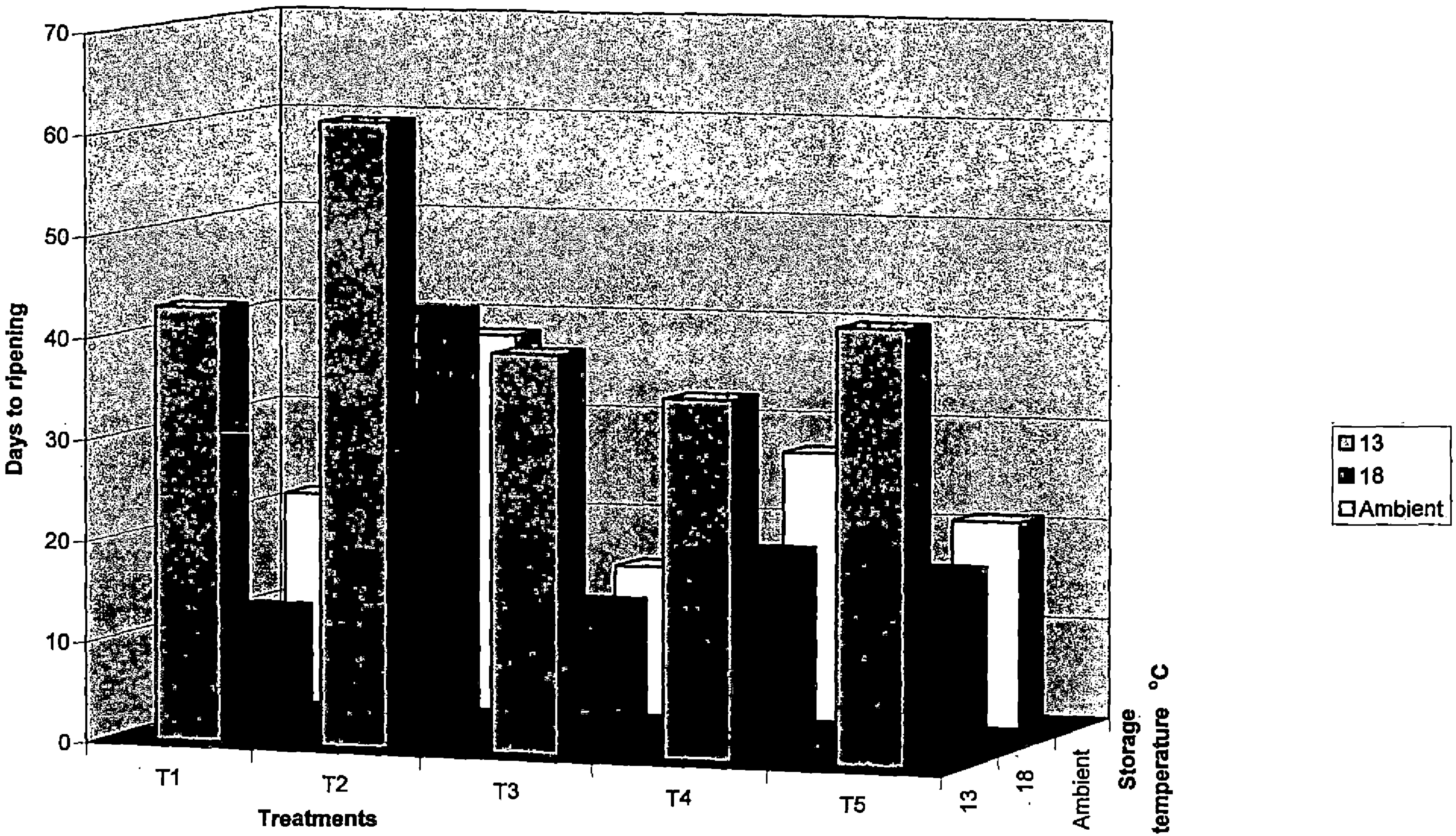
Precooling with iceflakes reduced the PLW in post-storage in open condition, after storing at 18°C and in ambient temperature. Precooling with iceflakes for five minutes did not show any symptoms of chilling injury. The reduction in PLW might be due to the removal of heat from the fruit and thus reducing the respiration rate as well as other processes causing transpiration.

5.2.3. Effects of storage temperature on days to ripening and green-life

Low-temperature prolonged the preclimacteric phase. The increase in the storage life of banana stored at low-temperature was reported by Scott and Gandanegara, (1974), Peacock, (1980) and George and Marriott (1983).

Of the 'Nendran' banana kept under three storage temperatures, the fruits stored at 13°C recorded the maximum days to ripen when compared to the hands stored at 18°C and in ambient temperature without developing any symptoms of chilling injury (Fig 3). krishna Murthy, (1989) reported a shelf-life of more than four weeks when stored at 15°C and four weeks when stored at 20°C in Robusta banana. Lower the storage temperature, the higher the CO_2 and lower the oxygen concentrations that developed in polybags (Hewage *et al.*, 1995). A logerithemic relation of green-life of CV.Monsmuri, over a range of 60-96°F was reported by Blakes and Peacock (1971). Scott and Gandanegara (1974) reported an exponential decrease in green-life with the temperature rise. Senorita bananas showed slow rate of respiration and no defined climacteric when stored at 15 °C (Esguera *et al.*, 1992).

Fig. 3. Effect of different storage temperatures on days to ripening of 'Nendran' banana



'Nendran' banana stored along with an ethylene absorbent recorded the maximum storage life of 49 days at 13°C, after which the fruits did not show normal ripening qualities in post-storage. The fruits stored at 18°C and ambient temperature recorded a maximum storage-life of 35 days each, after which the fruits ripened in the storage it self. A shelf-life of six weeks in 'Nendran' stored in MA packing at 13°C was also reported by Prasad *et al.* (1993).

Being a climacteric fruit banana goes into ripening phase, with the accumulation of a small amount ethylene in the storage. The presence of an ethylene absorbent helps to reduce build up of ethylene concentration in the storage environment there by increasing the green-life of stored banana. In absence of an ethylene absorbent, ethylene accumulates in the container and reaches physiologically active concentrations to initiate climacteric process and this reduces the green-life irrespective of storage conditions. Increase in storage life of CV. Bluggoe (ABB), Pacific plantain (AAB), Blue Cubin (ABB) and Pisang Awak (ABB) by a factor of three when an ethylene absorbent was placed and further increase in storage life by reducing the storage temperature from 18-13°C was given by Satyan *et al.* (1992).

Ethylene production at 13°C is 0.1µl 1kg.hr for mature-green bananas and it is 0.2-8µl/kg-hr-1 at 18°C (Kadar, 2000), which is almost double the amount of ethylene produced at 13°C. This high ethylene concentration in storage at 18°C would have stimulated the fruits to ripen. Whenever the ethylene production rate of banana in storage was lower than the detectable level (0.1µl/kg-hr) throughout the storage period, banana was found to be green and firm at the end of storage, (Liu, 1976). Maintenance of these ethylene levels at 13°C by ethylene absorbent would have resulted in improved green-life.

5.2.4. Effect of storage temperature on shelf-life and marketability.

Shelf-life is the time span over which the ripe fruit remains acceptable for consumption. Rippon and Trochoulias (1976) reported that shelf-life was affected not only by temperature during the shelf-life period but also by the temperature prior to the period or ripening. In confirmation to this finding in the present study banana hands stored at 13°C showed longer/extended shelf-life (6.00 to7.00 days) over those taken out from 18°c(5.33to 6.00 days). The fruits taken out from ambient storage recorded the shortest shelf-life (3.00 to6.00days) among the three storage temperatures.

The reduced shelf-life in ambient condition might be due to the accelerated ripening at high temperature and there by enzymatic action causing quick deterioration of the fruit. Reduction in storage temperature as the most important methods of precooling the shelf-life of fruits was given by Salukhe and Desai (1984).

Precooling in cold water 15°c for ten minutes and hotwater 50°c for five minutes followed by storage of 'Nendran' banana at 13°c improved marketability of 'Nendran' banana. Precooling with iceflakes for five minutes followed by storage at 13°c improved marketability. Storing with ethylene absorbent improved marketability in all the storage conditions studied. Ethylene absorbent and precooling would have reduced the respiration rate there by weight loss. The improved marketability of the hot water treated bananas might be due to the reduced microbial load of pathogenic organisms. This is an agreement with the reports of Thompson (1996) on the successful control of anthracnose caused by *Colletotrichum* sp. by immersing fruits in hot water before storage or marketing. The effect of hot water dip in controlling the growth of fungi on banana axis disk, was reported by Lopez *et al.* (1998).

Storage at 13°C not only increased the green-life but also improved shelf-life of the fruits when kept in open condition from the storage environment. The increase in shelf-life would enable the traders to have their produce in marketable condition over an extended period of time,

5.2.5. Effect of storage temperature on biochemical constituents

Increase in acidity during ripening of banana was reported by many workers. Mallic acid and citric acids are the major organic acids in banana. Acidity changes may be connected with changes in the mechanism of the respiration process (Aziz *et al.*, 1976). The acidity of conventionally ripened 'Nendran' at full-ripe stage is about 0.313%.

'Nendran' banana stored at 13°c recorded high acidity (0.56%-0. 98%) when kept in open condition for ripening compared to those stored at 18°c (0.50-0.66%) and in ambient temperature (0.41-0.61%)

The organic acids present in the fruit are respired or converted to sugars and decline during the greater metabolic activity that occurs in ripening (Wills *et al.* 1989). Storage at 13°C reduces the O_2 level and increases the CO_2 levels. CO_2 atmospheres seemed to check the normal decrease in acidity usually experienced in storage. The possible reason for acid accumulation during his storage might be lowered respiratory activity, increased CO_2 fixation or the presence of a less active enzyme that converts malic acid to pyruvate or oxalo acetate (Allen and Smock, 1937). This might be the probable reason for increase in acidity in storage at 13°C.

5.2.6. Effect of storage temperature on organoleptic qualities

Banana hands stored with ethylene absorbent showed maximum scores for organoleptic qualities.

The fruits kept in open condition for post-storage study were found organoleptically acceptable. This suggests that a post-storage ripening is essential for realizing optimum organoleptic quality of 'Nendran' banana. Though the fruits were of acceptable quality, slightly deficient quality with respect to colour, texture, aroma and taste in Robusta banana after one week of storage at 15°C was reported by Murthy (1981). In the present study also fruits stored at 13°c showed slightly low scores than those stored at 18°c and ambient temperature in organoleptic quality. Report of sweet flavour in fruits of senorita banana ripened at 25°C, 30 and 35°C than those ripened at 13°C was given by Esguera *et al.* (1992).

Low-temperature storage showed a considerable increase in the green-life and shelf-life of 'Nendran' banana. Post-storage studies showed that the fruits were acceptable organoleptically upto 49 days of storage at 13°C.

Though storage at ambient temperature and 18°C showed an extension in green-life they ripened in the storage before 40 days and 18°C being a favourable temperature to initiate banana ripening with high humidity (Salunkhe and Desai, 1984) it cannot be recommended as an ideal storage temperature. So storage at 13°C could be recommended where the fruits are required in green condition over a long storage time.

5.3. Experiment III

5.3.1. Development of packages for retail marketing of banana *Musa* (AAB) 'Nendran'

The primary function of package is to contain and protect the produce. The package size should be designed taking into consideration the customers requirements and also the specific attributes of the commodity to be packaged. A produce package is a dynamic system inside which respiration and gas exchange by the commodity occur simultaneously. These involve uptake of O_2 by the produce and evolution of CO_2, C_2H_4 and water and other volatiles from it. At the same time restricted permeation of these gases occur through the film used for packaging (Hening, 1975).

The present experiment was designed to find a suitable package for retail marketing of 'Nendran' banana, which not only improves the storage life of fruits but also retains the quality of the fruits.

5.3.2. Effect of packaging treatments on PLW of 'Nendran' banana

Packaging in polyethylene bag is known to reduce PLW. Of the packaging treatments tried, banana hands packed in vacuum pack and in unventilated polyethylene bag did not differ significantly in PLW and recorded a PLW of 1.76% and 3.2% respectively on the 35th day of storage. When an ethylene absorbent was placed in the package the PLW recorded was 1.66% and 2.69% respectively. The ethylene absorbent would have indirectly reduced the rate of respiration by reducing the rate of ripening.

PLW of 1.5% over 4-6 weeks of storage in vacuum pack was reported by Nair and Tung (1992). Rajeev (1996) and Rajeev and Sreenarayanan (1998) reported reduced PLW in vacuum packed fruits. Emeralad and Sreenarayanan (1999) recorded a PLW of 2.10 % in vacuum pack with ethylene absorbent in CV. Rasthali. A PLW of 0.1%, in banana after nine to eleven days of packing in sealed polyethylene bag was reported by Scott *et al.* (1971). Reduced PLW in banana fruits packed in 300 or 400 guage non-perforated polyethylene pack was reported by (Sarkar *et al.*, 1995).

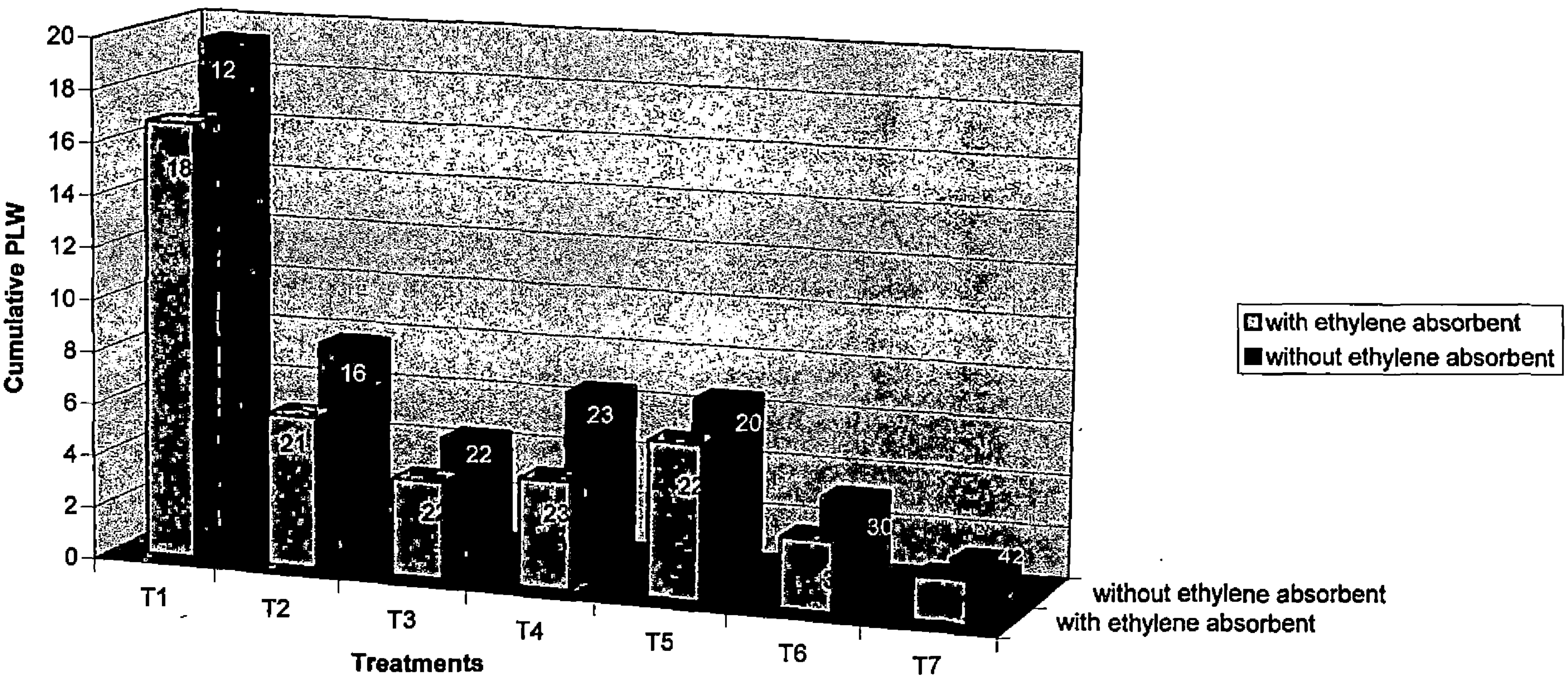
Reduced PLW in the fruits packed in polyethylene bag could be attributed to the high humidity developed in side the polyethylene bag making the air saturated with water vapour. This situation would have reduced the chances of water loss from fruit.

Packaging in polyethylene lined CFB boxes also reduced PLW compared to the hands packed in CFB box without lining material. The polyethylene lining would have created a humified atmosphere around the fruit thus reducing moisture loss. The lining material would also have restricted air movement within the CFB box. Slower respiration of 'Prata' banana, wrapped in polyethylene film was reported by De *et al.* (1988). A cheaper method of storing the fruit is to wrap the fruits in polyethylene film. Two types of polyethylene films D 950 and XDR have been found to reduce fruit weight loss by evapo transpiration (Marchal and Nolin, 1996). Reduced weight loss, in banana wrapped in polyethylene film was reported by Rao and Chundawat (1986) and Robinson (1996).

Banana hands whose cut ends were treated with Waxol-12% showed reduced PLW than the hands packed in polyethylene lined CFB box. This showed that, the loss of water could be restricted by sealing the cut ends with wax based formulations. Reduction in PLW in Dwarf Cavendish bunches whose cut stem surfaces were applied with paraffin wax was reported by Muthuswamy *et al.* (1971).

Water loss is loss of saleable weight and thus is a direct loss in marketing (Wills *et al.*, 1989). Packing in polyethylene bag or wrapping in polyethylene sheet showed reduction in the physiological loss in weight (Fig 4) from the produce because of reduced air movement across its surface. Application of Waxol-12% to cut ends reduced the weight loss further. Thus a package involving Waxol-12% application to cut ends and polyethylene film would maintain the saleability of the produce for more days under open conditions.

Fig. 4. Cumulative PLW of 'Nendran' banana in different packages



Note: Storage Life in days is marked at the top end of the bars

5.3.3. Effect of packaging treatments on days to ripening of 'Nendran' banana

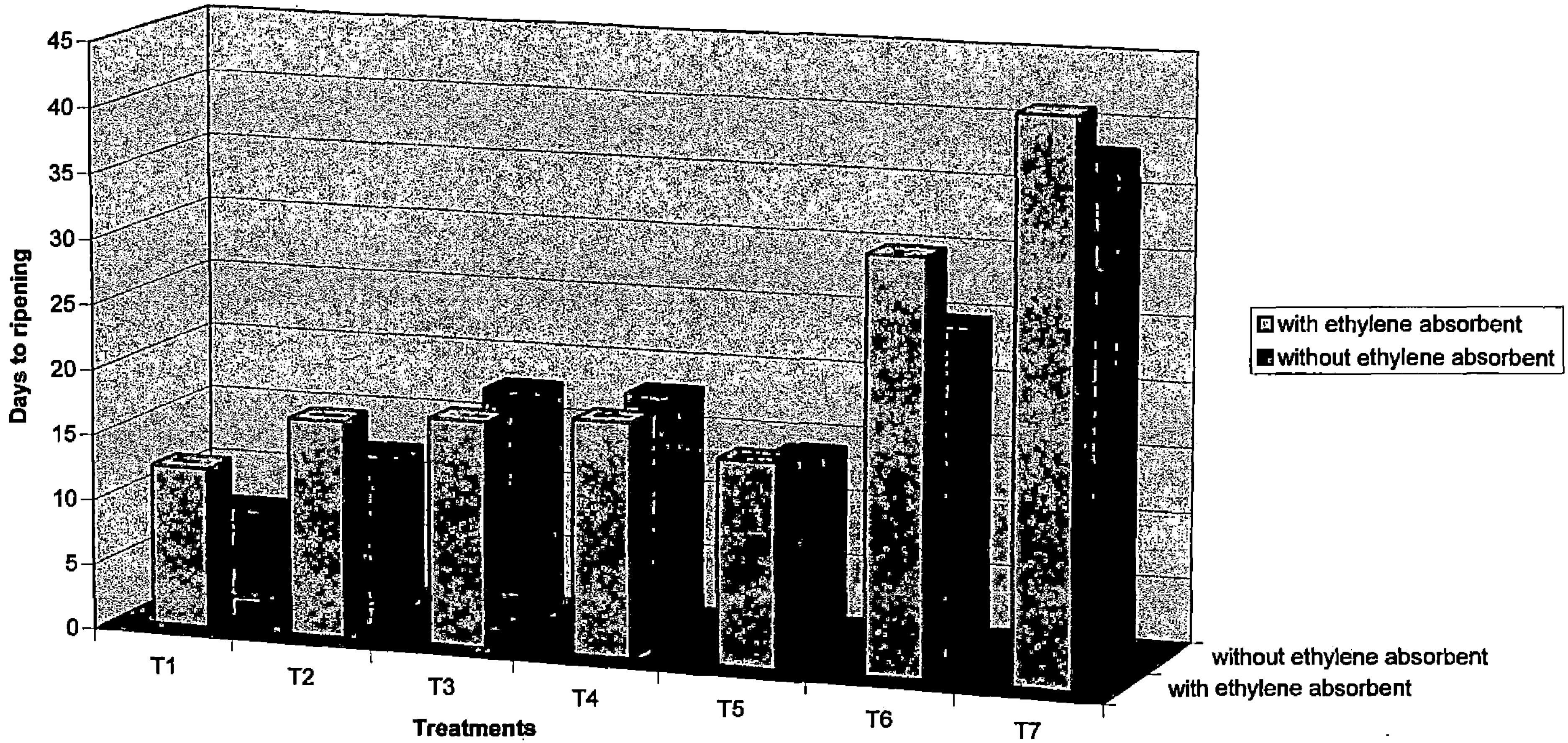
Results of the present study showed that vacuum packed hand recorded green-life of 38.00 days. Inclusion of an ethylene absorbent in the package increased the green-life to 42.67 days.

Rajeev and Sreenarayanan (1998) reported a storage life of 40 days in CV. Rasthali when packed in vacuum with an ethyelene absorbent. This is in agreement with the results of the present study where 'Nendran' showed a storage life of 42 days in vacuum packed condition. Emerald and Sreenarayanan (1999) reported a storage life of 30 days in CV. Rasthali and the fruits showed symptoms of spoilage after 30 days of storage even though they remained green and unripe and they attributed it to Co_2 injury to banana in prolonged storage under vacuum condition.

'Nendran' banana hands packed in unventilated polyethylene bag also recorded more days to ripening (31 days) when packed with an ethylene absorbent. Packaging polyethylene bag created a modified atmosphere where a build up of Co_2 in the package due to utilization of O_2 for respiration in turn, retard respiration (Ferris, 1997). Similar opinion for the increase in storage life in unventilated polyethylene bags was given by Quazi and Freebairn (1970) and Gorris and Peppelonbos (1992). Fruits of Gaint Governor remained in marketable condition upto 28 days after harvest when packed in non-perforated polyethylene packs of 300-400 guage.

Banana hands packed with ethylene absorbent recorded more days to ripen (i.e.) more green-life compared to the same package without ethylene absorbent (Fig. 5). Increased storage life of banana when packed with ethylene absorbent was

Fig. 5. Effect of different packaging treatments on days to ripening of 'Nendran' banana



also reported by Scott and Gandanegara (1974), Jayaraman and Raju (1992), Srikul and Turner (1995) and Naik and Tangaraj, 2000).

An increase in storage life by two to three fold when the bunches of cv. William were held in sealed polyethylene tube and three to four fold when an ethylene absorbent was packed with the bunch in the polyethylene tube was reported by Satyan *et al.* (1992).

'Nendran' banana hands packed in CFB box lined with polyethylene film showed increased green-life by four days over the hands packed in CFB box. This is in confirmation to the findings of De *et al.* (1988) in 'Prata' bananas, which recorded a delay in ripening by four to six days in ambient condition when wrapped with polyethylene lining. The polyethylene lining would have produced the same effect as polyethylene bag, but because of lack of sealing in polyethylene lined packing, the modified atmosphere in the package would not have been maintained that intact, which would have increased the ethylene concentration above the threshold level to initiate the climacteric process at an earlier stage.

Plantains stored in polyethylene, which had holes in it, ripened at the same speed as unwrapped fruit, although the speed of ripening was more variable in fruits packed in perforated polyethylene (Thompson *et al.*, 1972). The present study also confirms these findings, the fruits in unventilated polyethylene bag ripened in 15.67 days and the control ripened in 12.33 days. In ventilated polyethylene bag because of ventilation the gas surrounding the fruit in the package could almost be similar to the atmospheric air composition, which might be the reason for the similar behaviour of unwrapped and ventilated polyethylene packed fruits. Punctured bags did not allow the development of appropriate atmosphere (Woodruff, 1969).

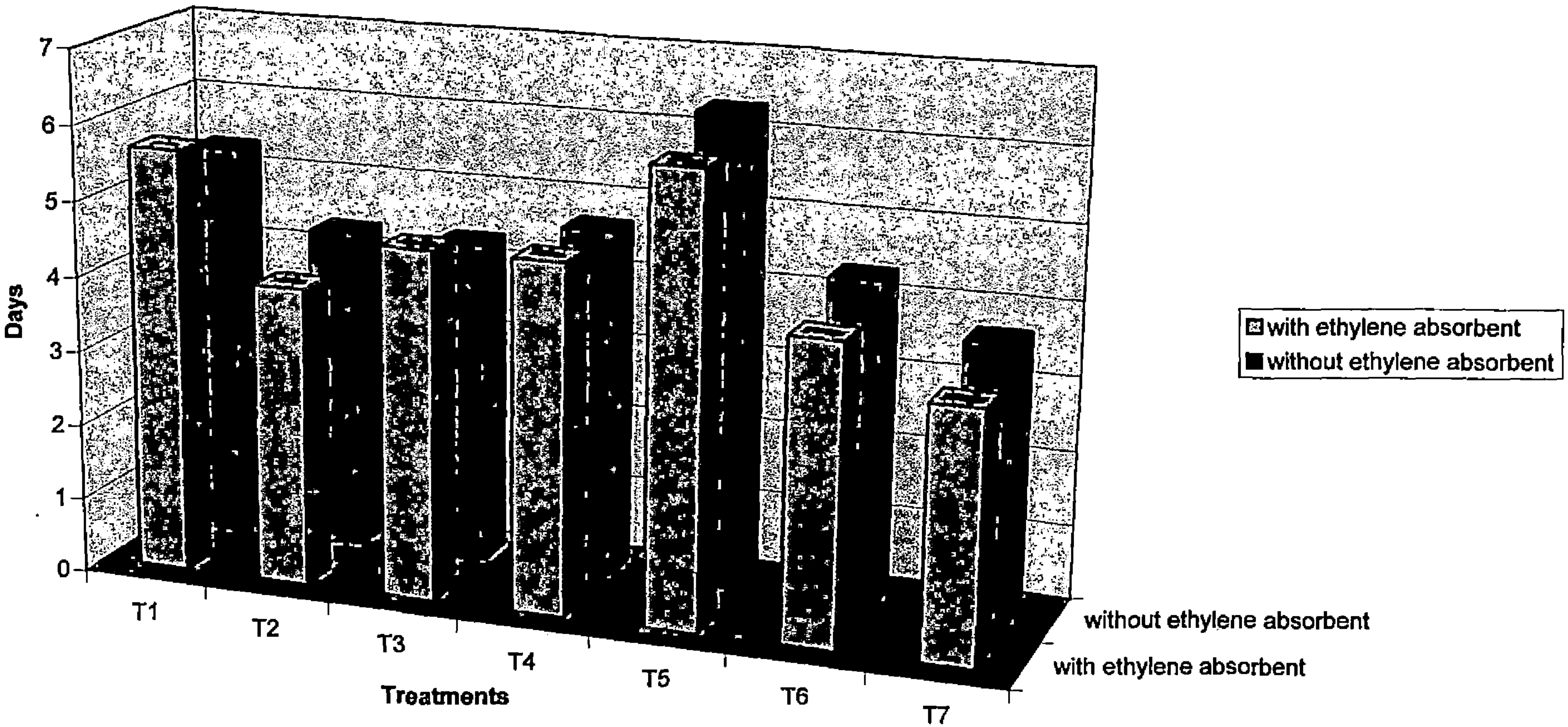
Packing in polyethylene bag and wrapping in polyethylene sheet showed an extended green-life over unpacked fruits by creation of modified atmosphere around the fruit. Placing an ethylene absorbent in the package increased the green-life further. These packages would be of use where the fruits are to be stored for a long time in green condition under ambient temperature. This would also reduce the extra cost addition on account of low temperature storage.

5.3.4. Effect of packaging treatments on shelf-life and marketability

Shelf-life is the time over which the ripe fruit remains edible and with a market acceptability. 'Nendran' banana hands packed in unventilated polyethylene bag and the hands packed in CFB box recorded more shelf-life compared to other treatments (Fig 6). The increased shelf-life might be due to reduced incidence of spoilage in less humidified atmosphere. The vacuum packed fruits recorded less shelf-life due to the incidence of spoilage due to fungal growth. Banana hands stored in unventilated polyethylene bag also showed less marketability, which could be due to the incidence of spoilage in high humid conditions inside the package. Rotting of the fruits packed in polyethylene bag with and without $KMnO_4$ due to high Co_2 concentration was reported by Aravindakshan (1981). Rotting of banana in sealed polyethylene bag was also reported by Scott *et al.* (1971).

Banana hands packed in CFB box and in ventilated polyethylene kept in open condition showed marketability up to six days, but the marketable percentage was less. This increased marketable period might be due to increased shelf-life provided by ventilated conditions resulting in reduced spoilage. This is in confirmation to reports of least spoilage (30.1%) in fruits stored in poly bags of 100 guage with 0.4% ventilation compared to control (88.5%) in sapota by Joshua and Sathiamoorthy (1993). Superiority of storage of Banganapalli mangoes stored in polyethylene bags of 250 guage with 1.0% ventilation with

Fig. 6. Effect of different packaging treatments on shelf-life of 'Nendran' banana



regards to rotting and maintenance of optimum quality was reported by Gautam and Suryanarayana (1996).

Packaging in ventilated polyethylene improved marketability and shelf-life of the fruits, but packing in unventilated polyethylene and vacuum pack recorded low shelf-life and marketability due to decay of fruits in the package. The advantage of improved green-life and reduced PLW would be of further use if the marketability and shelf-life of these fruits are improved. For this it could be suggested that the fruits be removed from the package and ripened in air, just prior to its marketing.

5.3.5. Effect of packaging treatments on biochemical constituents of 'Nendran'

'Nendran' banana hands packaged in vacuum recorded reduced acidity, T.S.S, T.S, R.S and starch content (Fig 7 and 8). In vacuum packed fruits, as the air from the package is fully evacuated, the gaseous composition of the air would be different from the other packages, which could have affected the changes in the biochemical constituents during ripening. The reduction in acidity might be because of more rapid use of organic acid during respiration or due to the ripening changes in pulp occurring in advance to the changes in peel.

'Nendran' banana hands packaged in vacuum pack with ethylene absorbent were found effective in extending the green-life. The cost of packing, one hand of 'Nendran' banana in polyethylene bag under vacuum with ethylene absorbent account to Rs.3.43 and the cost of packing in polyethylene bag with ethylene absorbent would be about Rs. 2.47 (Appendix III).

'Nendran' banana packed in CFB box + polyethylene lining + cut ends coated with Waxol-12% and CFB box + polyethylene lining + cut ends with

Fig. 7. Effect of different packaging treatments on Acidity, TSS and Brix:acid ratio of 'Nendran' banana

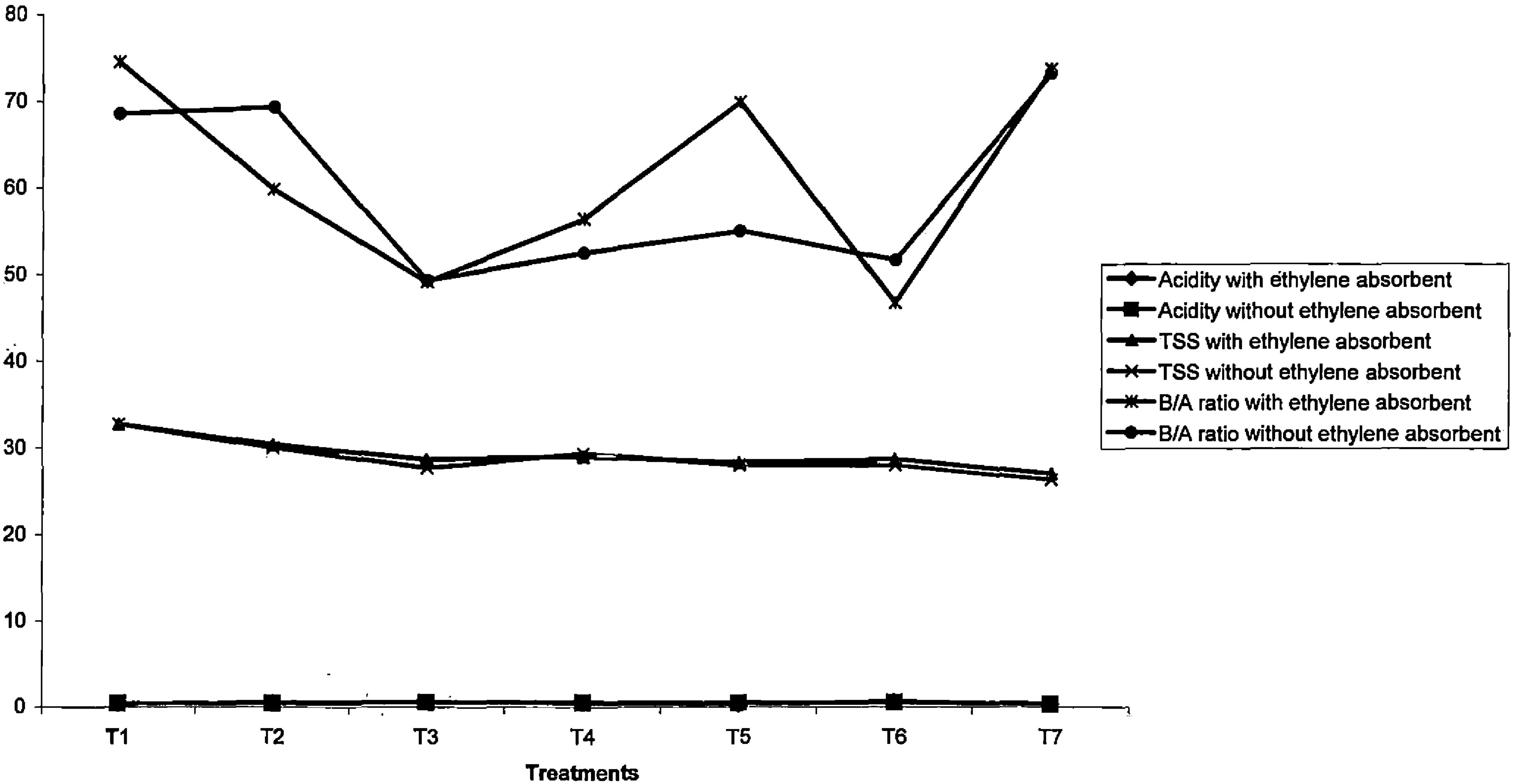
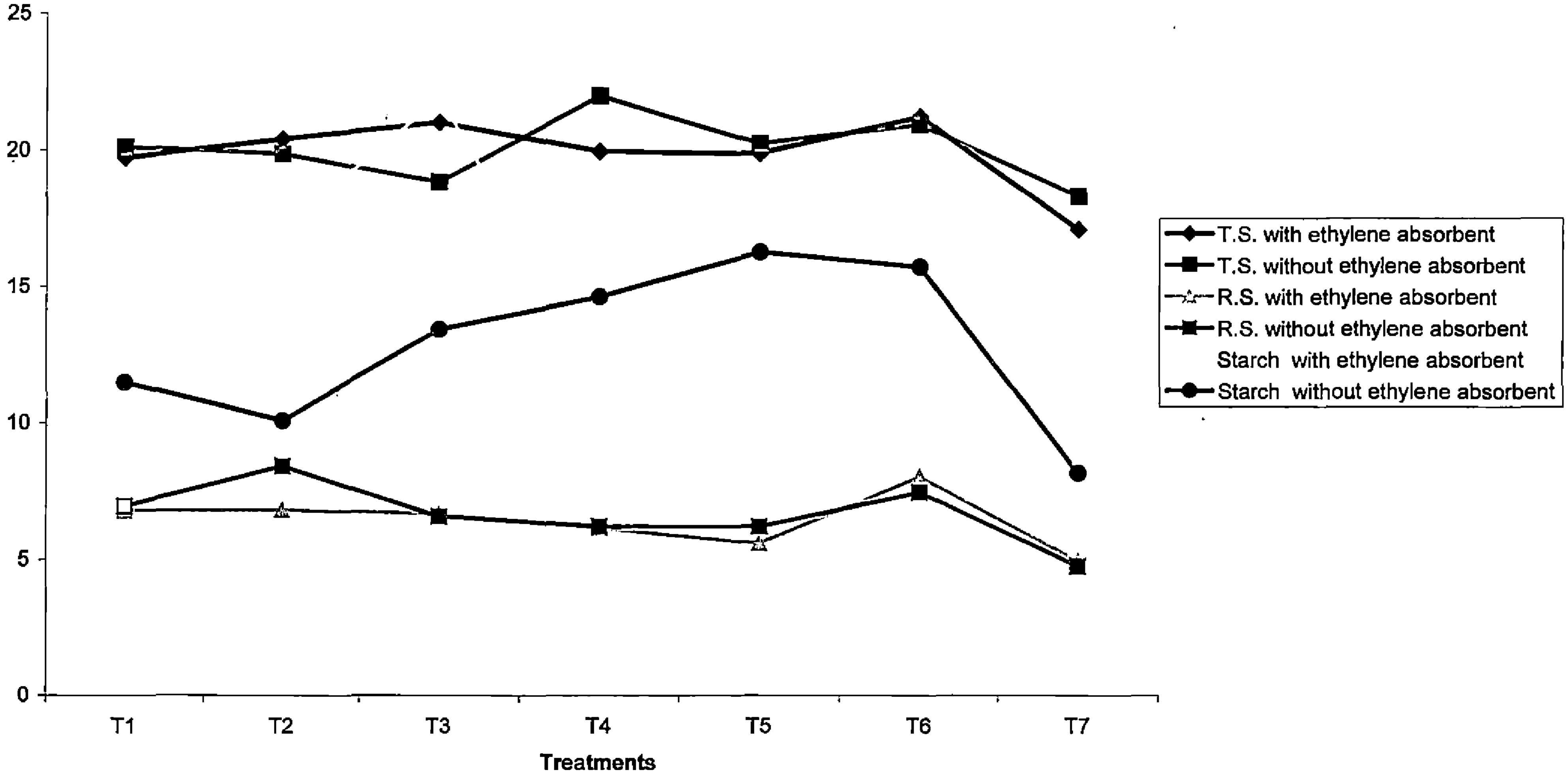


Fig. 8. Effect of different packaging treatments on total sugars, reducing sugars and starch content of 'Nendran' banana



(Waxol-12% + Bavistin (1000 ppm)) showed an extended green-life over banana packed only in CFB box and they also recorded high score for acceptability organoleptically. Packing of 'Nendran' in CFB box + polyethylene lining + cut ends coated with (Waxol-12% + Bavisitin (1000 ppm)) would cost Rs. 10.19/pack of two hands and packing in CFB box + polyethylene lining and cut ends coated with Waxol-12% would amount to Rs. 10.09/pack.

Packing in CFB box would serve the primary function of packaging to protect and to contain the banana fruits safely. CFB box could be conveniently stacked without damage to the fruits in the lower most boxes where as packaging just in a polyethylene bag though serves the purpose of containing and to some extent protect from bruising will not permit stacking, which would be a problem in the transportation and storage of 'Nendran' banana.

Packaging in CFB box lined with polyethylene sheet with cut ends coated with Waxol-12% and Bavistin (1000 ppm) showed similar effect as the CFB box lined with polyethylene sheet with cut ends coated with Waxol-12% but there is problem of residual Bavistin in the Bavistin treated fruits. So the former package could be suggested as a suitable package for storage at ambient conditions, without damaging the fruit. But considering the cost involved in packing this package could be suggested only for distant market, which could be reached within 15 days, as the fruits showed ripening after 15 days within the package. If the destined market is still far off then packaging the hands in polyethylene bag with ethylene absorbent in a CFB box could be suggested.

For the local supermarkets, where the purpose of package is besides moderately extended storage life, is to contain and display, packing in ventilated polyethylene bag could be suggested. Ventilated polyethylene bag would reduce the PLW, thus preserving the freshness of the fruit. Ventilated polyethylene could be conveniently used for pre-packing where the banana are pre-weighed and packed into convenient small units for retail sale.

5.4. Experiment IV

5.4.1. Development of grading system for banana *Musa* (AAB) 'Nendran'

'Nendran' bananas are generally retailed as hand as a unit, and cost is realized on basis of weight. In the present system, the customer purchasing the last hand on the bunch has to pay the same price as to that of the first hand, since the cost for 'Nendran' banana is generally fixed as a flat rate on per kilogram basis. There is lot of variation in size, weight, pulp content etc. between the banana hands. The fruits from bottom hands of a bunch look less mature and less full and more number of fruits would be required to make a kilogram of fruits. But the consumer is paying the same price to fruits irrespective of their size and appeal. Grading system of banana hands based on physical parameters would help the consumer to get a properly defined product for his money and also the farmers , to get good returns for their quality produce. This system will ultimately tempt the farmers to produce bunches confirming to top grades.

Since 'Nendran' bananas are mostly grown in Kerala and Tamilnadu for domestic consumption, no scientific attempt for grading of 'Nendran' banana was done earlier. But 'Nendran' is the most important commercial banana variety of Kerala. Hence an attempt to suggest a few guidelines for 'Nendran' banana would be of benefit to the farming community.

An attempt was made through this study to suggest a broad grading system for 'Nendran' banana, based on selected physical parameters

Various parameters considered were number of fingers/hand, length of the finger, girth of finger, curvature of finger, weight of finger and weight of hand.

In international market banana hands are graded mainly based on the length and grade or diameter of the fingers. Finger length preferences vary from country to country. Girth is measured to know the fullness of the fruit. The length and girth of the fruit decreased with the increase in number of hands in a bunch (Fig 9).

Curvature of fruit has good relevance in packing of fruits as well as in appeal. The study revealed that fruits with curvature less than 1.2 and more than 1.3 are not very much acceptable. Greater the curvature more, is the inconvenience in arranging the hands in a package. When the curvature of fruits is more packaging density was found to be reduced.

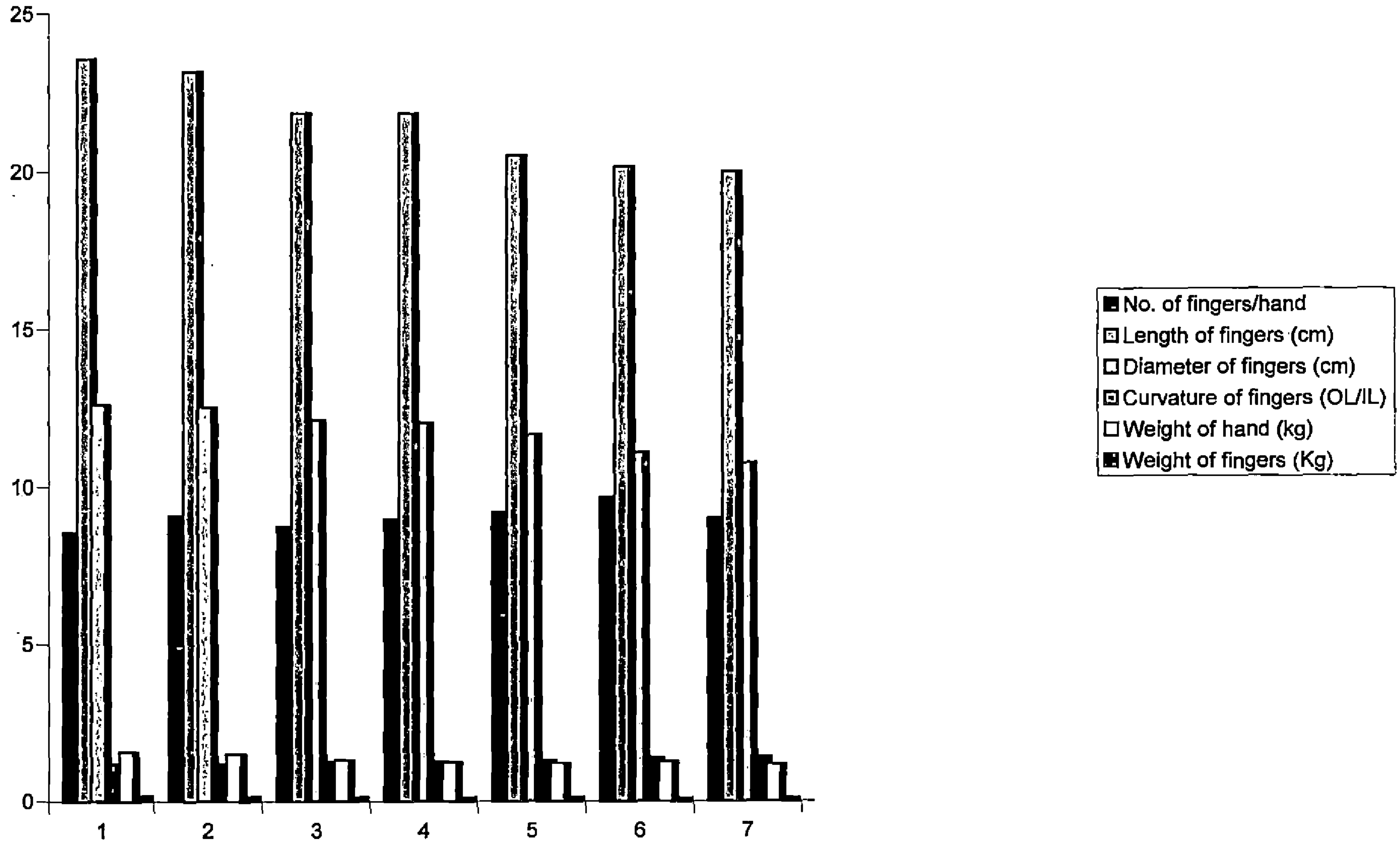
The weight of hands in a bunch varied between the hands (Fig 9). While five to six fruits of upper hands made kilogram, eight to nine fruits of lower hands were required for the same.

From the results of the study 'Nendran' banana could be conveniently graded into four grades.

The four grades did not differ much in the number of fingers/hand, which was around nine fingers in all the grades.

The finger length of Grade A fruits was more than 23.0 cm and Grade A and Grade D differed by about 2.5cm in length. The minimum finger length accepted in markets of Germany, Denmark and Netherlands is 20cm and the maximum length is 23-26cm (E.C.Guidelines, 1994). Charles and New (1996) reported that the smaller bananas are found at one end of the stem, and in general a range of fruit sizes will be

Fig. 9. Variation of physical parameters between the different hands of 'Nendran' banana in a bunch



within one box. And they specified a "standard" pack where fruit is over 7.5" length and "small banana" pack where fruits range from 5.5 to7.5 ".

The girth of fingers differed by 2.5cm between the first and last grades. The fingers of first grade showed a girth of 12.5 to13.0cm showing fullness of the fruits. The fruits with more girth are preferred to the ones with less girth and the present study also shows that, hands with more girth were given a better score.

The curvature of the finger of the first two grades is the same and this curvature was found to be acceptable curvature. This shows that grades A and B are convenient for packing.

Grades A and D differed in weight of hands by 500 g which indicates the requirement of more fruits of last grade to make a kilogram of fruits. The weight of individual fingers also proves the same.

For export and long distance market hands of the grade 'A' could be recommended, because of their length and girth being maximum. The overall appeals of such hands are generally high. A differential pricing system for hands within a bunch can be deliberately introduced in marketing of 'Nendran' banana for benefit of producers and consumers.

The hands of grade A and B could be proposed for dessert purpose in the local super markets and also for distant markets.

Hands of Grade C could be proposed for dessert purpose in the local market to consumers with less purchasing power enabling them to get more fruits of reasonable quality at a lower price.

In the present marketing system 'Nendran' bananas are sold on a 'whole bunch basis' at the retailers point. Thus a customer interested in A grade banana are forced to purchase bunches with B, C and D grade hands, which may ultimately be even discarded. This is an unfortunate situation. Thus scientifically defined marketing system of "Nendran hands" as marketing units instead of whole bunches is a need for efficient marketing of 'Nendran' banana.

At the retail level, whether the fruit is in a super market, green grocer or market stall, the principle feature in the presentation of bananas is the appearance of the fruit. The customer looks for a bunch or hand in which the bananas are unblemished with perfect skin free from scars, bruises and other defects (Charles and New, 1996).

Fruit defects like latex stains; blemishes and bruising were not taken into account in the present study. A further improvement in grading could be done by classifying the fruits considering the defects. Classification and scoring for defects could be done as given by Stover and Simmonds (1987).

Popularization of techniques and systems for grading would encourage farmers to produce quality produce, which will entitle them get better returns.

Summary

SUMMARY

The present study Postharvest handling and packaging system for banana *Musa* (AAB) 'Nendran' was conducted in the Department of Processing Technology, college of Horticulture, Vellanikkara during 1998-2000 and the results are summarized below.

1. Treatments involving ethrel (vapour\dip) and smoke filling were found effective in enhancing ripening of 'Nendran' banana. However, these treatments were on par with respect to their efficiency of ripening enhancement.
2. Ethrel (Vapour\dip) recorded maximum score for overall acceptance. 'Nendran' banana ripened in ethylene vapour filled chamber recorded maximum score for appearance and flavour and those dipped in ethrel solution (1000ppm) recorded maximum score for taste (7.5-8.0).
3. Smoke filling as a treatment for accelerated ripening of 'Nendran' though found to be effective, has disadvantages like smoky odur and poor appeal due to blemishes. Smoke filling treatment also has the risk of causing fire hazards.
4. Storing 'Nendran' bananas in ethylene vapour filled chamber for ripening was found to be a fast, easy, economic and safe method.
5. Precooling in cold water (15°C) for ten minutes \ hot water (50°C) for ten minutes followed by storage at 13°C improved marketability of 'Nendran' banana. Precooling with iceflakes for five minutes followed by storage at 18°C improved marketability of 'Nendran' banana.
6. 'Nendran' banana kept in open condition form the storage environment of 13°C showed an increase in shelf-life (6.00-7.00 days) over those taken from 18°C (5.33 to 6.00 days) and from ambient temperature (3.00 to 6.00 days).

7. 'Nendran' banana hands precooled with cold water (15°C) for ten minutes \ iceflakes for five minutes \ hot water of 50°C for ten minutes and those stored with and without ethylene absorbent recorded more days to ripen when stored at 13°C, compared to the same treatments stored at 18°C and ambient temperature.
8. Maximum storage life of 49 days with a subsequent normal post-storage ripening behaviour was observed in the storage of 'Nendran' banana at 13°C in presence of ethylene absorbent ($KMnO_4$).
9. Storage with ethylene absorbent sachet reduced the PLW and improved the marketability of 'Nendran' banana in all the three storage temperatures studies viz. 13°C, 18°C and ambient.
10. 'Nendran' banana stored at 13°C recorded high acidity (0.56% - 0.98%) when kept in open condition for ripening compared to those stored at 18°C (0.50% - 0.66%) and in ambient condition (0.41% - 0.61%).
11. Fruits ripened at 18°C and ambient temperature were organoleptically more acceptable than the fruits ripened after storage at 13°C.
12. Of the different packages tried ventilated (2%) polyethylene bag (100 guage) and CFB box improved the marketability of the fruits.
13. Polyethylene lining and application of Waxol-12% to cut ends were effective in reducing PLW of 'Nendran' banana when compared to packaging in CFB box.
14. 'Nendran' banana hands packaged with and without ethylene absorbent in unventilated polyethylene (2.68% and 3.2% respectively) and vacuum pack (1.66% and 1.76% respectively) recorded the lowest PLW over the other packages studied. Packaging with ethylene absorbent resulted in lesser PLW over the package without ethylene absorbent.
15. 'Nendran' banana hands packed in CFB box recorded the minimum days to ripening (7.00 days) while maximum duration was given by packing in vacuum with an ethylene absorbent sachet (42.67 days) to ripen.

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16. 'Nendran' banana hands packed with and without ethylene absorbent in unventilated polyethylene bag (5.33 and 5.00 days respectively) and those packed in CFB box (6.00 and 6.33 days respectively) recorded the maximum shelf-life and vacuum packed fruits with and without ethylene absorbent recorded lowest shelf-life (3.33 and 3.67 days respectively) as a result of increased microbial spoilage.
17. Packaging in vacuum reduced the T.S.S, acidity, total sugars, reducing sugars and starch content of the fruits and these fruits were found unacceptable organoleptically at the ripe stage.
18. 'Nendran' banana hands coated with Waxol-12% or Waxol-12% + Bavistin (1000ppm) at cut ends and packed in polyethylene lined CFB box were organoleptically superior to other treatments.
19. Guide lines to grade 'Nendran' banana with 'hands' as units based on the number of fingers/hand, weight of hand, length of finger, girth of finger, curvature of finger, weight of finger etc. revealed the possibility of grouping different 'hands' in a bunch of 'Nendran' banana into four grades of A, B, C and D.
20. Grade 'A' (hands with finger length more than 23.00cm, girth of 12.5 to13.0cm, curvature of 1.2 to1.25, with hand weight of about 1500 to1600g and finger weight 160 to175g) are recommended for distant and elite markets and Grade A and Grade 'B' (hands with length of 22.0 to23.0cm, girth of 12.0 to12.5cm, curvature of 1.2 to1.27 with hand weight about 1250 to1500g and finger weight about 140 to160g) are recommended for the local super markets. Grade C (hands with length of 20.5 to 22.0cm, girth 11.5 to12.00cm, curvature of 1.25 to1.3 and hand weighing 1200 to1250g with finger weight of 130 to140g) fruits can be recommended for dessert purpose in local market for people with low purchasing power. Grade D (hands with finger length less than 20.5cm, girth less than 11.5cm, curvature of 1.3 to1.4, hand weight of 1000 to1200 g and finger weight of 110 to130 g) could be recommended for sale as seconds for dessert purpose in the local market or for culinary purpose.

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Appendices

Appendix – I

Meterological data during the experimental period

Month	Week No.	Temperature (°C)		RH (%)	RF (mm)	Sun-shine hours (mean)	Wind velocity kmph (mean)
		Maxi-mum	Mini-mum				
July '99	25	29.6	23.1	87.5	114.7	3.7	2.5
	26	29	22.9	86	124.6	3.1	2.6
	27	26.9	22.8	94.5	326.5	0.5	2.3
	28	27.7	22.7	89	182.8	1.1	2.4
August '99	29	28.7	23.3	89.5	194.1	2.7	2.5
	30	29.5	23.7	84.5	121.5	5.2	2.8
	31	30.6	24.1	81	8.9	7.5	2.4
	32	30	23.6	81	3.2	6.9	2.3
	33	30	23	82	7.1	5.3	2.1
September '99	34	30	23.2	80	18.3	4.9	1.9
	35	31	23	78.5	10.1	8.1	2.2
	36	32.6	23.4	73	0	8.5	2.6
	37	32.9	23.8	75	0	6.4	2.1
October '99	38	30.5	23.1	82	80.5	4.8	1.4
	39	31.5	23.6	85	185.7	6.8	1.9
	40	29.5	23.3	87.5	161.6	2.9	1.9
	41	31.3	23.5	83.5	38.8	5.5	1.4
	42	29.6	22.7	84.5	41.9	6.2	1.4
November '99	43	31.4	22.1	74.5	2.8	7.8	1.4
	44	31.9	22.1	60	0	10.1	3.3
	45	31.1	23.5	62.5	4	6.3	5.4
	46	31.9	23.7	65.5	0	8.7	6.8
December '99	47	31.8	21.6	64	0	9.4	4.7
	48	31.8	22.6	63.8	0	8.1	4.1
	49	31.4	22.6	59.5	0	8.7	7.8
	50	31.4	23.4	55.5	0	8.8	8.8
January '00	1	32.2	23.8	58	0	9.6	8.5
	2	31.9	24.3	62.1	0	7.6	8.7
	3	33.5	22.4	57.5	0	9.5	5.1
	4	33.8	22.1	60.5	0	9.9	5.3
	5	33.7	19.9	57.5	0	10.1	7.3
February '00	6	33.2	22.9	71.5	0	7.2	2.9
	7	34.2	23.0	62	0	9.3	4.1
	8	33.2	22.6	74.5	0	8.7	2.5
	9	33.9	23.8	64	4.6	8	4.5

Month	Week No.	Temperature (°C)		RH (%)	RF (mm)	Sun-shine hours (mean)	Wind velocity kmph (mean)
		Maxi-mum	Mini-mum				
March '00	10	35.1	23.3	71.2	6	9.5	2.9
	11	34.8	23.9	69.3	0	9.6	2.7
	12	35.9	23.8	66.4	0	9.9	3.1
	13	36.3	24.7	69.5	0	9.2	2.5
April '00	14	33.3	23.6	76.1	0	5.5	2.1
	15	34.2	24.9	73.5	14	7.6	2.7
	16	34.1	24.5	73	0	8.4	2.4
	17	34.2	25.1	71	2.9	6.9	3.2
	18	34.4	25	70.5	4.5	8.4	2.9
May '00	19	34.9	25	68	0	9.3	3
	20	31	24.5	71	46.4	9.1	3
	21	32.8	24.2	77	60.2	7.2	3
	22	31.6	23.5	80	38.1	5.9	2.7
June '00	23	28.9	22.4	89.5	319.7	2	3.6
	24	30	22.8	84.5	106.9	3.3	2.9
	25	29.6	23.2	84.5	55.9	3.1	3.8
	26	29.4	22.5	84.5	104.3	4.1	3.4
July '00	27	28.9	22	84.5	87.8	1.5	3.8
	28	29.2	21.5	84	170	3.5	3.8
	29	30.1	22.8	39.5	48.9	5.7	4
	30	30.9	23.2	77	5.9	8.5	3.7
	31	31.1	23.6	80.5	9	6.4	3.2
August '00	32	29	22.8	87	93.3	2.5	3.6
	33	29.4	22.6	85.5	139.5	4.1	2.7
	34	27.7	22	91.5	232.8	0.3	3.8
	35	29.4	22.1	83.5	44.2	4.6	3.6

Source: Department of Agrometeorology, College of Horticulture, Vellanikkara

Appendix – II

Temperature and relative humidity in ambient conditions during the experimental period

Month	Week	Temperature	Relative humidity
June '00	1	25.6	87
	2	26	82.5
	3	26	83
	4	26	83
July '00	1	25	84
	2	25.5	82
	3	26.5	76.5
	4	27	75.5

Appendix – III

Cost analysis of different packaging treatments

a) Cost of packaging in CFB box with waxol – 12% and Bavistin (1000 ppm) coated at cut ends

Particulars	Amount (Rs.)
Cost of CFB (1 no.)	5.00 / box
Cost of 100 guage polyethylene sheet (60 × 60 cm) @ Rs. 60/- per kg	1.00
Cost of ethylene absorbent ($KMnO_4$ + vermiculate) 2 sachets	1.66
Cost of fungicide treatment (Bavistin @ Rs. 110/- per kg)	0.11
Cost of waxol-12% @ Rs. 150/- per litre	0.75
Labour cost for packaging, sealing and preparation of ethylene absorbent and dipping in waxol-12% with efficiency of packaging 12 packets per hour	1.67 / pack
Total	**10.19 / pack**

b) Cost of packaging in polyethylene bag

Particulars	Amount (Rs.)
Cost of 100 guage polyethylene bag 35 × 30 cm @ Rs. 80/- per kg	0.80
Cost of ethylene absorbent ($KMnO_4$ + Vermiculite)	0.83
Labour cost for packaging, sealing and preparation of ethylene absorbent at efficiency of packing 24 packets per hour	0.84
Total	**2.47 / pack**

C.F.B. box, polyethylene sheet and polyethylene bag could be reused which would further reduce the cost on packaging on commercial scale.

c) Cost of vacuum packaging

Particulars	Amount (Rs.)
Cost of 100 guage polyethylene bag 35 × 30 cm @ Rs. 80/- per kg	0.80
Cost of ethylene absorbent ($KMnO_4$ + Vermiculite)	0.83
Cost of engine oil @ Rs. 45/- per litre (¼ HP motor)	0.10
Power consumption of 0.4 units per hour (efficiency of packing 30 packs per hour)	0.03
Labour cost for packaging, sealing and preparation of ethylene absorbent at efficiency of packing 12 packets per hour	1.67
Total	**3.43 / pack**

POSTHARVEST HANDLING AND PACKAGING SYSTEMS FOR BANANA *Musa* (AAB) 'NENDRAN'

By

NALLAMOTHU GOUTHAMI

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the requirement for the degree

Master of Science in Horticulture

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ABSTRACT

The present study on 'Postharvest handling and packaging systems for banana *Musa*(AAB) 'Nendran' was conducted in the Department of Processing Technology, College of Horticulture, Vellanikkara during 1998-2000. In the first experiment the efficacy of ethrel (Vapour and dip) was compared with smoke filling to induce early ripening of 'Nendran' banana. The results revealed that ethrel vapour\dipping and smoke filling treatment as effective ripening agents. Ethrel (vapour\dip) treated fruits were found organoleptically superior in all quality parameters tested. Ethrel vapour treatment was found to be a fast, easy, economic and safe method for ripening of 'Nendran' banana. Smoke filling as a treatment for accelerated ripening of 'Nendran' though found to be effective, had the disadvantage of smoky odur, poor appeal due to blemishes, and it also posed the risk of fire hazards.

Studies to develop a suitable technique for extension of shelf-life of 'Nendran' revealed that precooling in cold water of 15^0c for ten minutes and hot water (50°C) treatment for ten minutes improved the marketability of 'Nendran' banana stored at 13°C. Pre-cooling with iceflakes for five minutes improved the marketability when stored at 18°C. Storage at 13°C along with placement of an ethylene absorbent sachet was effective in extending the storage life up to 49 days without impairment of post-storage ripening as well as fruit quality. Placement of an ethylene absorbent sachet in the storage was effective in extending the storage life, improving the marketability and reducing the PLW irrespective of the storage temperature. The decrease in the storage temperature reduced the PLW.

The attempts to develop a package for retail marketing of 'Nendran' banana revealed that packaging in CFB box and ventilated polyethylene bag extended the

shelf-life and enhanced the marketability of the fruits. Polyethylene lining (100 guage) and coating of cut ends with Waxol-12% reduced the PLW and extended green-life over those packed in CFB box. Vacuum pack and unventilated polyethylene bag (100 guage) were also effective in reducing PLW and also in extending the green-life of the fruits. However vacuum pack failed to give optimum ripening quality. 'Nendran' banana coated with Waxol-12% and Waxol-12% + Bavistin (1000 ppm) at cut ends and placed in polyethylene lined CFB box were organoleptically more acceptable than the fruits kept in the other packages.

An attempt was made to suggest broad guidelines for developing a grading system for 'Nendran' banana with hand as a unit revealed that 'Nendran' banana hands could be conveniently graded into four grades (A, B, C, D) based on parameters like weight of hand, length, girth, curvature and weight of finger. Superior grades A and B can be recommended for export, distant and elite markets, super markets etc. for dessert purpose. Grade C can be recommended for dessert purpose for the people with low purchasing power. And Grade D for sale by local vendors as seconds for dessert purpose or for culinary purpose. Grading helps to identify the storage worthiness of banana for end use of table purpose and trend to market 'Nendran' banana as hands can enable the farmers to produce quality fruits, which will fetch a better price to the farmers.