POSTHARVEST MANAGEMENT STUDIES IN PINEAPPLE (*Ananas comosus* (L.) Merr.)

By

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(2011-12-107)

THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Postharvest management studies in pineapple (*Ananas comosus* (L.) Merr.)"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

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INTRODUCTION

1. INTRODUCTION

Pineapple (*Ananus comosus* (L.) Merr.) is the leading edible member of the family Bromeliaceae and a native of Brazil and Paraguay. The unique fruit quality and high productivity under marginal conditions make pineapple a commercially important fruit crop. The edible portion of pineapple is composed of 77-91% water and 9.7-12% sugar which together make up over 98% of the fruit (Ray, 2006). Pineapple contains considerable amount of calcium, potassium, fibre and vitamin C, but is low in fat and cholesterol. It is also a good source of vitamin B1, vitamin B6, copper, phosphorus, iron and dietary fibre. Pineapple is a digestive aid and a natural anti-inflammatory fruit. A group of sulphur-containing proteolytic enzymes called bromelain in pineapple aids digestion.

In India, the major producing states of pineapple are West Bengal, Assam, Karnataka, Meghalaya, Manipur, Bihar and Kerala. Total area, production and productivity of pineapple in the country during 2010-11 is 89,000 ha, 1415000 tons and 15.9 tons/ha respectively (NHB, 2011). Export potential is also high for this crop. International market requires standardized high quality produce. To achieve this quality, postharvest management practices are to be improved. Increased requirement of pineapple in cosmopolitan cities, demands long distance marketing, from the centres of production.

Pineapple cultivation in Kerala is a profitable entrepreneurship due to the soil and climate prevalent in Kerala. Emergence of new market avenues also makes the cultivation of pineapple an enterprising business. In Kerala, it is cultivated in an area of 12500 ha with a production of 102400 tons and a productivity of 8.2 t/ha, consistently stable over the last few years (NHB, 2009).

Kew and Mauritius are the two important varieties recommended for large scale commercial cultivation in Kerala. The variety Kew is considered good for processing, but the variety Mauritius has gained more importance in Kerala owing to its better keeping quality, short duration, better taste and flavour as compared to Kew.

'Mauritius' is also known as 'European Pine', 'Malacca Queen', 'Red Ceylon' and 'Red Malacca' in international trade. The variety Mauritius is popular in India, Malaya and Ceylon. Mauritius is exclusively grown for table purpose but it is sold fresh and can be utilized for making juice. Due to its high market preference and consumer acceptability commercial cultivation of Mauritius is extensive in Ernakulam, Kottayam, Pathanamthitta and some parts of Idukki districts. Since the pineapples grown in these areas are traded from Vazhakulam in Ernakulam district, it is known by the name Vazhakulam Pineapple and the same has acquired GI registration. Currently, Vazhakulam is known as the centre of pineapple trade in Kerala and India.

Huge loss during postharvest period is the major problem associated with pineapple. Not only are losses clearly a waste of food, but they also represent a similar waste of human effort, farm inputs and livelihood. After harvest, the pineapple is subjected to spoilage due to mechanical damage, physiological disorders, diseases, moisture loss and normal deterioration process. The quality at this stage is influenced by factors such as temperature, relative humidity, postharvest treatments and handling method. Therefore, postharvest handling plays an important role in maintaining the quality of the fruit after harvest until the consumption stage. Proper handling is also needed to reduce postharvest losses both quantitatively and qualitatively.

The total postharvest loss in pineapple has been estimated to be at 29.25 per cent, comprising 2.19 per cent loss at the farmer's field level, 16.39 per cent at wholesale level and 10.67 per cent at the retail level (Gajanana *et al.*,2002). Awareness and adoption of loss saving practices at fruit setting and harvest, and selection of appropriate marketing channels would help to reduce the postharvest losses in pineapple.

Postharvest management activities start immediately after harvesting of fruits. Maturity at the time of harvest is important in determining the eating quality of pineapple. The small difference in maturity of pineapple after harvest makes a large difference in eating quality and consequently consumer satisfaction (Smith and Harris, 1995). Harvesting at correct stage and good storage conditions help to increase the shelf life of pineapple. It is necessary to determine the precise degree of maturity at which fruits with desirable qualities are to be harvested for commercial purpose. The problem with fresh pineapple is not how to store the fruit so that it can be ripened for use by the consumer, but rather how best to store the fruit to minimize loss of its original quality. Refrigeration and postharvest sanitation treatment delays quality deterioration during storage and shipping.

Pineapple is traded mainly in fresh form and that too in a limited scale mostly to the neighbouring regions like Middle East, due to its highly perishable nature. Water loss and postharvest decay account for most of the losses. These have been estimated to be more than 20-30 per cent in the tropics and sub tropics. Methods to prevent postharvest losses in pineapple include proper harvesting, handling, storage and packaging techniques.

Hence the present study was taken up to standardize the harvesting and handling practices for minimization of postharvest losses in pineapple. The specific objectives of the study are

1. Standardization of harvesting and storage method
2. Standardization of postharvest treatments and storage temperature

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Pineapple, the queen of fruits is one of the most popular fruits of the tropical region. Kerala is the most important pineapple growing state with an area of 12,500 ha. A considerable amount of the produce is lost during handling, transportation, transit and storage. During transportation, a substantial quantity of pineapple is damaged due to improper harvesting, rough handling, absence of packaging systems and rough road (Deka *et al.*, 2005).Hence postharvest management of fruits is necessary to reduce the loss to a considerable level. A brief review of various aspects of harvest maturity, method of harvest and storage, post harvest treatments and storage temperature of pineapple fruits is presented here.

2.1 Harvest maturity

The physico-chemical characteristics of fruits change significantly with maturity (Chandra and Kar, 2003). These changes, lead to certain post harvest constraints like short shelf life, susceptibility to many diseases and pests and faster fruit ripening at warmer temperatures which limit its long duration storage and transportation (Giusti *et al.*, 2008; Sonkar *et al.*,2008). Although the fruit maturity is assessed subjectively by the fruit colour and days after fruit set, physical and chemical properties are determined objectively in the laboratory prior to harvesting, storage, transportation and marketing (Martins *et al.*, 2008). Further studies are required to define conditions for long duration storage and transportation to minimize losses.

2.1.1 Harvest maturity in pineapple

Pineapple is a non- climacteric fruit. As a non- climacteric fruit, obvious compositional changes after harvest are mostly limited to degreening and decrease in acidity (Kader, 1992). No quality improvement can, therefore, be expected after harvesting.

Maturity is important in eating quality of pineapple. Correct stage of maturity at harvest recommended was 20% yellow colour of the shell and the fruits harvested at this stage have attractive bright yellow flesh colour (Wijesinghe and Sarananda, 2002). Half yellow stage is regarded as ripe and at this stage brix and titrable acidity have reached their maximum. Full ripe fruits are unsuitable for transport to distant markets or for exports and a less mature grade must be selected (Ray, 2006). Pineapple for domestic market is harvested at the fully ripe stage while unripe but mature fruit are for the export market (FAO, 2006).

Colour of pineapple peel is an external factor that is used to determine the various stages of maturity (Joomwong, 2006). In Kew fruits, yellow colour development of the basal half to two-third portion of fruits is taken as the optimum stage of harvest for local market purposes. Whereas, if the fruits are to be transported to distant markets, harvesting when ⅓rd to ¼th basal portion of fruits become yellow is advisable, to prevent losses (Radha and Mathew, 2007).

Pineapple fruits harvested at different maturity stages are not of uniform quality (Dhar *et al.*, 2008). In India, pineapple is harvested when the colour changes from green to greenish yellow. The fruit develops smooth surface around the eyes, the bracts start drying up (John, 2008). In pineapple maturity index, the yellowish colour increases starting from peduncle and progress to the upper part of the fruit as the maturity stage increases (Rohana *et al.*, 2009). They also reported that although pineapple is considered as a non-climacteric fruit, the peel acts as a climacteric due to increase in peel colour after harvesting. It is reported by Abdullah in (2011) that the pineapple harvested at early maturity has poor organoleptic properties but longer storage life, whereas the fruit of advanced maturity is more pleasant in terms of physical appearance and organoleptic quality but the potential storage life is reduced.

2.1.2 Harvest maturity of other non- climacteric fruits

2.1.2.1 Citrus

The firmness of different citrus fruits declines with the advancement of maturity. Juice content in citrus fruits shows a positive correlation with the harvest maturity. Fully mature Nagpur mandarin fruits contain 43-44% juice (Ladaniya and Singh, 1998).

2.1.2.2 Grape

The concentration of soluble solids, pH and titrable acidity in fruit juice are more reliable parameters to determine the grape berry maturity and optimum harvest date (Uhlig and Clingeleffer, 1998).

2.1.2.3 Strawberry

The skin colour, taste and TSS to acid ratio are taken into consideration to judge the maturity of fruits. Among the maturity indicators, colour of the fruits is widely accepted maturity index by the growers and consumers (Ferriera *et al.*, 1994). Berries are usually harvested when 75% skin develops colour (Mokkila *et al.*, 1997).

2.1.2.4 Indian gooseberry

The fruit volume increases up to 75 days after fruit set, fruit colour changes from green to yellow green or reddish green, vitamin C and TSS increase up to 120 days after fruit set and this is the optimum stage for harvesting (Balasubramanyam and Bangarusamy, 1998).

2.1.2.5 Litchi

For local markets, litchi is ideally harvested when fully red and ripe (Underhill and Wong, 1990), whereas fruit intended for long shipping distances is often picked when the pericarp partly turns red or at 75–80% maturity (Shi *et al.*, 2001; Semeerbabu *et al.*, 2007). As a non-climacteric fruit, litchi does not improve in quality after harvest, but has to ripen on the tree (Chen *et al.*, 2001). All the varieties arrived at harvest maturity between 55 and 80 days after full bloom (Mahajan and Dhatt, 2002). The number of days from full bloom to harvest is considered to be the best maturity index for litchi fruits and for Shahi variety it is reported as 65- 72 days (Rai and Das, 2002). The most dependent maturity index for litchi is the attainment of fruit colour. The litchi turns deep red when it fully ripens (Mangaraj and Goswami, 2009).

2.1.3 Harvest maturity of climacteric fruits

2.1.3.1 Mango

The assessment of maturity in mangoes is mainly determined on the basis of shoulder growth and TSS (Kudachikar *et al.*, 2001). 'Banganpalli' should be harvested at about 8% TSS for air transport (APEDA, 2000). In some varieties, the fruit is considered to be mature when the shoulder outgrow the stem as in Alphonso (NHB, 2006).

2.1.3.2 Banana

Banana is harvested before full maturity in a green and hard condition. There is no definite way of determining maturity and growers and exporters rely mainly on fruit diameter and angularity of fingers (Jain *et al.*, 2004).

2.1.3.3 Sapota

Sapota takes around 200 days to mature from fruit set. Arrest of latex flow and change in fruit surface colour (potato colour) are the best maturity indices for sapota fruits. The fruit surface becomes smooth and scaly nature disappears (Asrey *et al.*,2008).

2.1.3.4 Papaya

Skin colour turning stage is attained at 130-135 days after fruit set and the fruit takes 155-160 days to reach eating ripe stage. The fruits harvested at colour break stage attain proper TSS (7-8%), total sugars (5-6%),acidity (0.096%) and sugar/acid ratio (50-55) at ripening (Ghanta, 1994). For export, fruits are harvested at colour break, or between colour break and one-quartet yellow colour to obtain maximum fruit life and quality (Shiesh, 2001).

2.1.3.5 Guava

Visual appearance and firmness test are important attributes for establishing the maturity index of guava. The number of days from full bloom to fully maturation in guava developed during rainy and winter season is reported to be 120-125 days and 95-100 days respectively (Adsule and Kadam, 1995).

2.1.3.6 Apple

Melvin and Little (1997) recommended the maturity indices for storage, which include background colour, firmness 7.5-9.5Kg, starch score 2.5-3.5, blush more than 60% and sugar level more than 13%. For Royal Delicious apple the days from full bloom to harvest maturity is 125-130 days (Ghosh, 1999).

2.1.4 Biochemical changes during postharvest period of pineapple

After harvest many changes occur in the chemical composition of pineapple fruits. Freshly harvested pineapple fruit contains 86% water, 8g sugars, 0.5- 1.6g acids, 1g protein, 0.5 g ash, 0.1 g fat, some fibre and vitamins (Pongjanta *et al.*, 2011).

The titrable acidity usually declines during storage of harvested pineapple (Paull, 1993). Proposed minimum soluble solids content and maximum titrable acidity for acceptable flavour quality in pineapple is 12% and 1% respectively (Kader, 1999).The typically yellow flesh is best eaten when sweet (10-18% sugar) and moderately acid (0.5-0.6% titrable acidity) (Bartholomew *et al.*, 2003). A mature pineapple for canning should have TSS 12 percent and acidity 0.5 to 0.6 percent (John, 2008). According to Moneruzzaman *et al.* (2008) during maturation and ripening of fruit there are changes in total soluble solids (TSS) and they reported TSS increases from mature green stage to yellow ripe stage. A minimum soluble solids content of 12% and a maximum acidity of 1% will assure minimum flavour acceptability by most consumers (Kumar *et al.*, 2009).

Byrne *et al.* (1991) reported that the sweetness of fruit is highly dependent on sugar composition because sugar differs in their relative sweetness. Masniza *et al.* (2000) reported that pineapple contains 12-15% sugar of which two-third or majority is in the form of sucrose and the rest are glucose and fructose. They also reported that the fully ripe fruits are unsuitable for transporting to distant markets and less mature fruits are selected in this case and immature fruits are not shipped since they do not develop good flavour, have low brix and are more prone to chilling injury. Sweetness is an important indicator of fruit quality and highly correlated with ripeness in most fruit (Ersoy *et al.*, 2007). According to Ishtiaq *et al.*, (2010), yellowness of the fruit is accompanied by progressive sweetness of the fruit pulp due to formation of sugars resulting probably from starch hydrolysis.

Kader (1988) reported that maturity at harvest, harvesting method and postharvest handling conditions affect the vitamin C content of fruits and vegetables. Ascorbic acid should fall between 20 and 65 mg/100g of fresh weight, depending on the cultivar and stage of maturity (Medina and Garcia, 2005). Fresh peeled pineapple fruit contains an average ascorbic acid content of 24.8 mg/100g of fruit (Uckiah *et al.*, 2009). The vitamin C content varies from 10 to 25 mg/ 100g of pineapple fruit (Pongjanta *et al.*, 2011).

2.2 Method of harvest and storage in pineapple

Pineapples are normally harvested manually. Chadha *et al.* (1998) suggested that harvesting should be done with a sharp knife, severing fruit stalk with a clean cut, retaining 3- 5 cm long stalk attached to fruit and the crown is not detached. The fruit should be broken off the stalk with a downward motion, or cut with a knife slightly below the base of the fruit. For the domestic market, this generally involves trimming of the stem at the base of the fruit to a length of 1-2 cm, removing any damaged or unsightly leaves in the crown, and a gentle dry brushing of the fruit surface to remove dirt and dust (Anon, 2002). Radha and Mathew (2007) reported that harvesting of fruit is done along with a piece of stalk by severing it by a sharp knife with a clean cut and the crowns are not generally removed from the fruit, since it results in bruises leading to infection. Harvesting of pineapple is to be done using a sharp knife by giving a smooth cut and the stem end should not be more than 2cm long (PRS, 2010).

Pineapple fruits in general are packed in baskets with bamboo strips or in plastic crates. A commonly used package in the international trade of pineapples is a full-telescopic two-piece corrugated fibreboard carton. Top and bottom ventilation, in addition to side vents are required, particularly where sea shipments are used. Typical carton inside dimensions are 30.5 cm wide x 45 cm long x 31 cm deep (Anon, 2002).The fruit after harvest is carried in trucks placing the crown downwards for cushioning (Medina and Garcia, 2005). Harvested fruits are placed in baskets, crates or bags by hand, upside down on the crown to avoid injury (Mohammed, 2004). While packing fruits, they are arranged in an upside down position so that the crowns act as a cushioning material preventing injuries or bruises. When transported in truck also, the fruits are packed in this fashion (Radha and Mathew, 2007).

2.3 Postharvest treatments

Postharvest treatments are given to prolong storage period without loss of quality. Conditioning of the produce namely curing, surface sanitation and chemical treatments with calcium compounds, growth regulators, fungicide, chlorine water and sprout inhibitors have been recommended to maintain quality of produce for a longer time (Pal and Sharma, 2010).

2.3.1 Surface sanitization

Use of a disinfectant in wash water can help to prevent both postharvest diseases and food borne illnesses. Chlorine is the most widely used sanitizing agent for fresh produce (Beuchat, 1998; Brackett, 1999). Chlorine-based chemicals, particularly liquid chlorine and hypochlorite, are probably the most widely used sanitizers for decontaminating fresh produce. Infiltration of calcium chloride into apples has been shown to control postharvest disease, delay senescence, and reduce physiological disorders (Conway , 1982). Huddar *et al.*, 1990 reported that calcium chloride treatment advanced ripening in banana. Chlorine compounds are usually used at levels of 50 to 200 ppm free chlorine and with typical contact times of less than 5 min (Watada and Qi, 1999; Francis and O'Beirne, 2002). Baur *et al.* (2005) reported that use of chlorinated warm water pre-washing was the best treatment to reduce total aerobic bacteria, pseudomonas and enterobacteriaceae. Postharvest washing of fresh produce, usually with chlorine is an important method for pathogen reduction (Warriner *et al.*, 2009). Chlorine in the form of sodium hypochlorite solution or a dry powdered calcium hypochlorite can be used in wash water as a disinfectant (Kumari, 2013). She also reported that calcium hypochlorite, beyond disinfection benefits, is reported to improve the shelf life and disease resistance of fruits and vegetables by adding calcium to the cell wall.

Organic acids (e.g. lactic acid, citric acid, acetic acid, tartaric acid) have been described as strong antimicrobial agents against psychrophilic and mesophilic microorganisms in fresh-cut fruit and vegetables (Bari *et al.*, 2005; Uyttendaele *et al.*, 2004). The antimicrobial action of organic acids is due to pH reduction in the environment, disruption of membrane transport and/or permeability, anion accumulation, or a reduction in internal cellular p^H by the dissociation of hydrogen ions from the acid (Beuchat, 2000).

The use of saturated alum solution has been found very effective in controlling soft rot in cabbage however it is phytotoxic (Kumari, 2013). Alum has a two-fold function to control bacterial soft rot; as an antimicrobial agent by direct kill and as a moisture withdrawing substance that deprives the bacterial pathogens of water.

Removal of heat from freshly harvested commodity without loss of quality is the most desired method for extension of storage life of perishables. Washing in cold water can reduce the field heat, hence the storage life can be prolonged (John, 2008).

2.3.2 Hot water treatment

Postharvest heat treatment is a non-contaminating physical treatment that delays the ripening process, reduces chilling injury and controls the activity of pathogens and hence are currently used commercially for quality control of fresh products

(Ferguson *et al.*, 2000). Hot water successfully eradicates incipient infections in several fruits. Produce may be immersed in hot water before storage or marketing to control diseases.

Many fruits and vegetables tolerate hot water temperatures of 50° to 60° C for up to 10 minutes, and the treatment can control many postharvest plant pathogens (Lurie, 1998). Mild heat treatment has been found to be a potent means of increasing the shelf-life of fruits while maintaining its sensory and nutritional attributes (William *et al.*, 1994; Paull and Chen, 2000; Wang *et al.*, 2001). Mild heat treatment of a number of horticultural crops has been reported to improve product quality and shelf-life (Wang *et al.*, 2001). Mild heat treatment has been reported to reduce microbial load and improve fruit texture and taste of a number of fruits (Valero *et al.*, 2002; Abreu *et al.*, 2003; Lamikanra *et al.*, 2005). Heat treatment technology is a safe and environmental friendly procedure with increasing acceptability in commercial operations. It is used successfully, to control the incidence of postharvest disease in several commodities (Fallik, 2004). Fruits after harvest dipped in hot water (45-55°C) for about few minutes can enhance uniform and rapid ripening and it will control the decay. It can be used to control fungal pathogens, spores and latent infections (John, 2008). Hot water treatment is highly effective in reducing the load of pathogens, which reduces the incidence of postharvest diseases during storage and transportation (Pal and Sharma, 2010). Rathore *et al.* (2012) reported that hot water dip is safe for controlling fungal growth in fruits which can tolerate hot water at 50° to 60°C up to 10 minutes but shorter exposure at the temperature can control many postharvest plant pathogens.

Internal browning, commonly encountered in pineapple during prolonged cold storage, is a major obstacle to long distance export of fruits under sea freight. According to Weeraheva.(2002), the cultivar Mauritius is more susceptible to internal browning than Kew. Heat shock treatment in the form of hot water dip immediately after harvest was found to induce fruit tolerance to internal browning in both Kew and Mauritius fruits. Relatively high temperatures and long period of treatment are capable of depleting the levels of vitamin C in pineapples (Padayatty *et al.*, 2003). The fruits treated at 38°C for 60 minutes developed 70% and 45% lesser browning in the flesh and core region respectively than the untreated controls (Weeraheva and Adikaram, 2005). Pre-storage heat treatments to control decay are applied for short periods of time (min), as target pathogens are present in the outer-most layers of host tissue. Three minutes hot water dip treatment at 54°C, applied to the trimmed peduncle of pineapple was very effective in controlling the incidence of black rot (Wijeratnam *et al.*, 2005). The fruit after harvest should be subjected to 53°C temperature for 5-7 minutes hot water treatment to kill the mealy bug, scale insects, thrips, mites and prevent from storage rots (PRS, 2010).

Fruit tolerance to chilling injury can be enhanced by heat treatment prior to storage (Klein and Lurie, 1992). Heat treatment at 38°C for 4 hours provided protection against chilling injury in mango (McCollum *et al.*, 1993) and in citrus (Rodov *et al.*, 1996). Chilling injury has also been reduced by treatment at 53°C for 3 min in oranges prior to cold storage at 3°C for 10 weeks (Wild, 1993). Chilling injury and external browning of avocado was reduced by heat treatment at 38°C for 120 min prior to storage at 0.5°C for up to 28 days (Woolf, 1997). In persimmon fruits, heat treatments reduced chilling injury associated symptoms of flesh gelling or flesh softening. This effect was observed when fruits were subjected to hot air treatments (Woolf *et al.*, 1997) or with hot water treatments (Burmeister *et al.*, 1997). Thermal postharvest treatments have also improved the quality and shelf life of pomegranate (Artes *et al.*, 2000). It is proposed that hot water treatment of Sapote Mamey at 60°C for 60 minutes may be useful in the shelf life extension of the fruit, as well as the control of fruit flies and internal rots (Diaz-perez *et al.*, 2001). Reduction of TSS content and lowering the sweetness are disadvantage of heat treatment. Heat treatments especially hot water treatment is widely used in many countries for insect and decay control in mango (Aveno and Orden, 2004). Hot water dip treatment of 1 min at 52°C slowed the rate of rot development in litchi (Olesen *et al.*, 2004).

2.3.1 Postharvest diseases and disorders in pineapple

Most of the microorganisms affecting shelf life of fresh-cut produce need an optimal environment with a relative humidity (RH) higher than 80 % for their growth (Frazier and Westhoff, 1993). Consequent to wounding during processing and microbial growth during storage, there is an increase in off-flavour compounds, loss of firmness and respiration, reduced fresh-cut shelf life that lead to senescence processes (Artés *et al.*, 2007). The microbial population of fresh-cut fruits and vegetables is determined to a large extent by the origin of fruits and vegetables, agricultural practices, conditions of harvesting, processing and storage (Fan and Song, 2008).

Black rot, also called *Thielaviopsis* fruit rot, water blister, soft rot, or water rot, is a universal fresh pineapple problem characterized by a soft watery rot (Rohrbach, 1983). Diseased tissue turns dark in the later stages of the disease because of the dark mycelium and spores. Black rot is caused by the fungus *Chalara paradoxa* (De Seynes) Sacc. The rot is commercially controlled by minimizing bruising of fruit during harvest and handling, refrigeration, and postharvest fungicides (Rohrbach and Phillips, 1990). The severity of the problem is dependent on the degree of bruising or wounding during harvesting and packing, the level of inoculum on the fruit, and storage temperature during transportation and marketing (Rohrbach and Schmitt, 1994).

Yeasty fermentation is caused by the growth of yeast on pineapple fruit which results in formation of gas bubbles and the juice escapes through the cracks in the skin (Paull, 1997). As a result the skin turns brown and leathery and the fruit becomes spongy with bright yellow flesh.

Saprophytes growing on the broken end of peduncle (*Penicillium* sp.) and fruit surface are non-pathogenic but are unsightly, and therefore a marketing problem (Rohrbach, 1989). The condition is more common on highly translucent fruit.

2.4 Cold storage studies in pineapple

Temperature is the most important factor affecting fruit storage life because all the physiological processes leading to senescence, like respiration and ethylene production are controlled by temperature (Wills *et al.*, 1998).

Ripe pineapple fruit can be held at 7.2°C for about 7 to 10 days. The maximum storage life at 7° C is about 4 weeks (Paull and Rohrbach, 1985).The optimum storage temperature for pineapple is between 7 to 13°C (Hardenburgh *et al.*, 1986). They reported that under that condition, pineapple can be expected to remain fresh for 2 to 4 weeks. Temperatures of 7- 12°C are recommended for storage of pineapples for 14 to 20 days, provided fruits are at the colour break stage (Paull, 1993). A relative humidity of 85- 95% is recommended, a high RH significantly reduces water loss. Recommended cold storage conditions are 10-13°C and 8-10°C for mature fruits and ripe fruits respectively, both at 85-90% RH. This condition increases shelf life to 3-4 weeks (Thompson, 1996). Malaysian pineapples at breaker colour stage can be stored for up to 4 weeks at 8-10°C (Abdullah and Rohaya, 1996). According to Chadha *et al.* (1998), the best storage is at 7.2°C and 80 -90% RH, although, at lower temperature with longer storage period, there is a marked increase in acidity. Accrding to Jobling. (2000), the optimal temperature for storage of pineapple fruit is 10°C in general, but very often they are prepared, shipped and stored below 10°C (Medina, 2004). Fruits harvested at green, colour break and 20% yellow stage can be kept for 10 days at ambient temperature (25± 2°C), compared to those harvested at 40% yellow, as they may be over mature hence undergo rapid senescence (Wijesinghe and Sarananda, 2002). For maximum postharvest life, pineapple fruit should be cooled to 8°C (47°F) as soon as possible after harvest and maintained at this temperature during transport to market. At this temperature, pineapples harvested at the quarter-yellow stage have a shelf life of approximately 3 weeks (Anon, 2002). Optimum storage life of pineapple at optimum temperature of 8- 10°C is 6 weeks. Pineapple when stored below 8°C develop brown/ dull skin colour, water soaked flesh, wilting of crown and also failure to develop full flavour at room temperature (John, 2008). Studies conducted by Abdullah *et al.*, 2009 revealed that the suitable storage temperature for Malaysian pineapple is between 8 to 10°C for a period of 3 to 5 weeks. Fruits harvested in early stage of ripening are stored at 7-10°C (Kumar *et al.*, 2009). The studies conducted at Pineapple Research Station showed that the pineapple fruit should be stored at 12° C at 85% RH (PRS, 2010). The storage of native pineapple fruit at 8°C is recommended because better fruit quality was retained at this temperature by preventing chilling injury and decay (Sanchez *et al.*, 2012).

There is a worldwide market for fresh pineapples but access to these markets is limited by their short storage life as the fruits are susceptible to fungal infections, development of internal browning (IB) and off flavours (Rohrbach and Johnson, 2003). IB is a form of chilling injury that develops when the fruit are stored at less than 15°C (Nukulthornprakit and Siripanich, 2005; Youryon *et al.*, 2008). IB of pineapple is a physiological disorder that develops when the fruit is exposed to low temperature during storage or in the field (Weerahewa and Adikaram, 2005). They also reported that the cultivar Mauritius is more susceptible to IB than Kew. IB develops initially in the flesh around the core of pineapple fruit (Youryon *et al.*, 2008).

2.4.1 Biochemical changes in pineapple during cold storage

All biological processes are controlled by temperature and the fruit quality is strongly affected by temperature (Fuchs *et al.*, 1995).

TSS is often used as an indicator of fruit quality and maturity level. Hong *et al.*, 2013 observed that during low temperature storage TSS increased initially and then decreased during the storage period, whereas titrable acidity increased initially and then decreased during the storage.

Generally, fruits and vegetables show a gradual decrease in ascorbic acid content as the storage temperature or duration increases (Adisa, 1986). He also reported that pineapple fruit stored at 5, 10 and 15° C could delay the loss of ascorbic acid. Joseph-Adekunle *et al.* (2009) reported pineapple fruit stored at 10° C had better texture and flavour than those stored at higher temperature.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present investigation on the "Postharvest management studies in pineapple (*Ananas comosus* (L.) Merr.)" was carried out at the Department of Processing Technology, College of Horticulture, Vellanikkara, Thrissur, Kerala during 2011-2013. Vellanikkara lies between 10°32' N latitude and 70°10' E longitude and 22.25 m above mean sea level. The area enjoys warm humid tropical climate throughout the year.

The whole programme was divided into 4 major experiments

3.1 Standardization of harvest method and stage of harvest in pineapple

3.2 Evaluation of storage method

3.3 Post harvest treatment studies

3.4 Optimization of storage temperature

Pineapple fruits were collected from the Pineapple Research Centre, Kerala Agricultural University, Vellanikkara which were maintained as per the package of Practice Recommendations of Kerala Agricultural University (KAU, 2011).

3.1 Standardization of harvest method and stage of harvest in pineapple

The fruits of four different maturity stages both by retaining and without retaining peduncle were harvested to standardize the best stage and method of harvest. The fruits after harvest were carefully transported on the same day to the laboratory. Spoiled or injured fruit were discarded.

3.1.1 Treatments

T_1- Fully mature, green colour fruits harvested by retaining 2cm length of peduncle

T_2 - Fully mature, green colour fruits harvested without retaining 2cm length of peduncle

T_3- 0-25% eye colour of fruits changed to yellow harvested by retaining 2cm length of peduncle

T_4- 0-25% eye colour of fruits changed to yellow harvested without retaining 2cm length of peduncle

T_5- 25-50% eye colour of fruits changed to yellow harvested by retaining 2cm length of peduncle

T_6- 25-50% eye colour of fruits changed to yellow harvested without retaining 2cm length of peduncle

T_7- 50-100% eye colour of fruits changed to yellow harvested by retaining 2cm length of peduncle

T_8- 50-100% eye colour of fruits changed to yellow harvested without retaining 2cm length of peduncle

3.1.2 Lay out

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

3.1.3 Evaluation of fruit characters

The fruits were harvested during the early hours of the day. Ten fruits per each treatment which were free from injuries were cleaned and stored at ambient condition.

3.1.4 Observations

Observations on both physical and chemical changes during storage were taken as detailed below

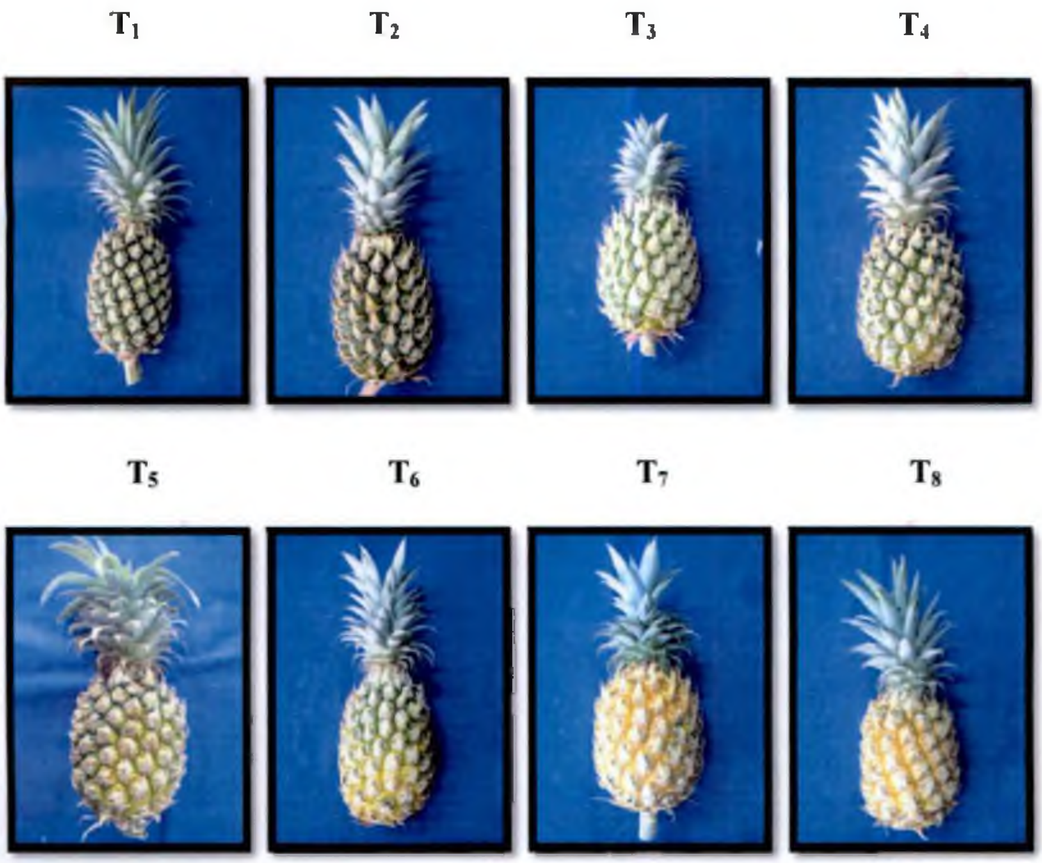


Plate 1. Stages and method of harvest

T_1 - Fruits harvested at fully mature green stage with peduncle.

T_2 - Fruits harvested at fully mature green stage without peduncle

T_3 - Fruits harvested when 0-25% eye colour changed to yellow with peduncle

T_4 - Fruits harvested when 0-25% eye colour changed to yellow without peduncle

T_5 - Fruits harvested when 25-50% eye colour changed to yellow with peduncle

T_6 - Fruits harvested when 25-50% eye colour changed to yellow without peduncle

T_7 - Fruits harvested when 50-100% eye colour changed to yellow with peduncle

T_8 - Fruits harvested when 50-100% eye colour changed to yellow without peduncle

3.1.4.1 Physical parameters

3.1.4.1.1 *Fresh weight (g)*

Fresh weight of individual fruits was recorded and expressed as gram.

3.1.4.1.2 *Physiological loss in weight (PLW)*

PLW was calculated on the initial weight basis as suggested by Srivastava and Tandon (1968) at three days interval and expressed as percentage.

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

3.1.4.1.3 *Blackening/browning*

Blackening/browning of the fruits was observed visually as black/ brown spots and lesions.

3.1.4.1.4 *Spoilage*

Spoilage of the fruits was observed visually as attack by pathogens or by mechanical injury.

3.1.4.1.5 *Shelf life*

The shelf life was calculated as number of days from harvest till the fruits remained marketable. The fruits were rated as not marketable when more than 50% of fruits in a lot showed incidence of spoilage.

3.1.4.2 Biochemical parameters

3.1.4.2.1 *Total Soluble Solids (TSS)*

TSS was measured /recorded directly using a digital refractometer (range 0-32°brix) and expressed in degree brix.

3.1.4.2.2 *Acidity*

Titrable acidity was estimated as per the procedure described by Ranganna (1997).

A known weight of the pulped fruit was digested with boiling water. An aliquot of the digest was treated with standard alkali using phenolphthalein as indicator. The acidity was expressed in terms of the most predominant acid in the fruit viz., citric acid.

3.1.4.2.3 *Total, reducing and non-reducing sugars*

Total sugars and reducing sugars were determined as per the procedure described by Ranganna (1997) using Fehling's solution in titrimetric method and expressed as percentage. The non-reducing sugars were obtained by subtracting the percent of reducing sugars from the total sugars.

3.1.4.2.4 *Ascorbic acid*

Ten grams of fruit was taken and extracted with four percent oxalic acid. Ascorbic acid content of the fruits were estimated by 2, 6-dichlorophenol indophenol and expressed as mg/100g of fruits (Sadasivam and Manickam, 1996).

3.1.4.3 *Sensory evaluation*

Sensory evaluation was carried out with the help of 15 member semi trained panel on a nine point hedonic scale. Hedonic rating scale method measures the level of liking of any product based on a test which relays on the people's ability to communicate their feelings of like or dislike. Hedonic ratings are converted to rank scores and rank analysis was done.

Score card including quality attributes like colour, taste, flavour, texture and overall acceptability was prepared for sensory evaluation of pineapple fruits. Each of the above mentioned qualities were assessed by a nine point hedonic scale. Score card used in the evaluation is given in Appendix I.

3.2 Evaluation of storage methods

The experiment was aimed at evaluating the shelf life of pineapple fruits stored under four methods. Fruits having 0-25% eye colour yellow harvested by retaining 2cm length of peduncle were stored under different methods.

3.2.1 Treatments

T_1 - Heaping and covering the fruits with 150 GSM silpaulin

T_2- Stacking fruits vertically with crown downwards

T_3- Stacking fruits vertically with crown upwards

T_4- Storing the fruits in paper cartons of standard size

3.2.2 Observations

Observations on both physical and chemical changes after storage were taken as detailed below.

3.2.2.1 Physical parameters

3.2.2.1.1 *Fresh weight (g)*

Fresh weight of individual fruits was recorded and expressed as gram.

3.2.2.1.2 *Physiological loss in weight (PLW)*

PLW was estimated as mentioned in 3.1.4.1.2

3.2.2.1.3 *Blackening/browning*

Blackening/browning was observed as mentioned in 3.1.4.1.3

3.2.2.1.4 *Spoilage*

Spoilage of fruits evaluated as in 3.1.4.1.4

Stacking fruits vertically with crown upward

Stacking fruits vertically with crown downward

Storing fruits in paper cartons

Heaping and covering with silpaulin (150 GSM)

Plate 2. Methods of storage

3.2.2.1.5 *Shelf life*

Shelf life of fruits evaluated as in 3.1.4.1.5

3.2.2.2 *Chemical parameters*

3.2.2.2.1 *Total Soluble Solids (TSS)*

TSS estimated as in 3.1.4.2.1

3.2.2.2.3 *Acidity*

Acidity estimated as in 3.1.4.2.2

3.2.2.2.4 ***Total, reducing and non-reducing sugars***

Total, reducing and non-reducing sugars estimated as in 3.1.4.2.3

3.2.2.2.5 *Ascorbic acid*

Ascorbic acid estimated as in 3.1.4.2.4

3.2.2.3 ***Sensory evaluation***

Sensory evaluation of fruit evaluated as in 3.1.4.3

3.3 Postharvest treatment studies in pineapple

Fruits harvested at the best stage, as obtained from the previous experiment were used for conducting post harvest treatment and storage studies.

3.3.1 Treatments

T_1- Immersing in cold water for 10 minutes

T_2-Immersing in 1% acetic acid for 10 minutes

T_3- Immersing in luke warm chlorinated water (100ppm) for 10 minutes

T_4- Immersing in alum (1000ppm) for 10 minutes

T_5 -Hot water dip treatment at 50° c for 1 minute

T_6 -Control

3.3.2 Observations

3.3.2.1 Physiological loss in weight (PLW)

PLW estimated as mentioned in 3.1.4.1.2

3.3.2.2 Total microbial load before and after treatment

The quantitative assay of microflora present in the above samples was carried out by serial dilution plate count method as described by Agarwal and Hasija (1986). Ten gram sample was added to 90 ml distilled water and shaken well to form a suspension. From this suspension, 1 ml was transferred to 9 ml distilled water. This gave 10^{-1}dilution. From the filtrate 1 ml was then transferred to test tube containing 9 ml distilled water. This gave a dilution of 10^{-2}. Later 10^{-3}, 10^{4}, 10^{-5}, 10^{-6} dilutions were prepared from this serial dilutions.

3.3.2.2.1 Estimation of fungal population

One ml of 10^{-3}dilution was pipetted into a sterile petridish using a micropipette. About 20 ml of the melted and cooled Potato Dextrose Agar (PDA) media was poured to the petridish and it was swirled. After solidification, it was kept for incubation at room temperature.

Three Petridishes were kept as replicate for each sample. The petriplates were incubated at room temperature for 4 to 5 days. The fungal colonies developed at the end of five days were counted and expressed as CFU/g of the sample.

3.3.2.2.2 Estimation of yeast population

The population was estimated using 10^{-3} dilution of the sample. The media used was Sabouraud Dextrose Agar medium and the same method was followed as in the estimation of fungal population. The dishes were incubated at room temperature for

4 to 5 days and the yeast colonies were counted and expressed as CFU/g of the suspension.

3.3.2.2.3 Estimation of bacterial population

Bacterial population was estimated using 10^{-6} dilution on Nutrient Agar medium. The method that was used for the estimation of fungal population was followed for estimation of bacterial population. The dishes were incubated for 48 hours at room temperature. The bacterial colonies developed were counted and expressed as CFU/g ofthe sample.

Composition of Nutrient Agar, Sabouraud Dextrose Agar and Potato Dextrose Agar are given in Appendix II.

Number of Colony Forming Units (CFU) per gram of the sample

$$= \frac{\text{Mean number of CFU x dilution factor}}{\text{Quantity of the sample on weight basis}}$$

3.3.2.3 Shelf life

Shelf life of fruits evaluated as in 3.1.4.1.4

3.4 Optimization of storage temperature

Fruits at best stage of harvest and given best post harvest treatment, as obtained from the previous experiment were used for optimizing storage temperature.

3.4.1 Treatments

T_1 – Ambient condition

T_2 – Storage at 8±2°C

T_3 – Storage at 14±2°C

T_4 – Storage at 20±2°C

Plate 3. Cold storage units

T_5 – Storage at 26±2°C

3.4.2 Observations

3.4.2.1 Physical parameters

3.4.2.1.1 Fresh weight (g)

Fresh weight of individual fruits was recorded and expressed as gram.

3.4.2.1.2 Physiological loss in weight (PLW)

PLW estimated as mentioned in 3.1.4.1.2

3.4.2.1.3 Blackening/browning

Blackening/browning was observed as mentioned in 3.1.4.1.3

3.4.2.1.4 Spoilage

Spoilage of fruits evaluated as in 3.1.4.1.4

3.4.2.1.5 Shelf life

Shelf life of fruits evaluated as in 3.1.4.1.5

3.4.2.2 Chemical parameters

3.4.2.2.1 Total Soluble Solids (TSS)

TSS estimated as in 3.1.4.2.1

3.4.2.2.2 Acidity

Acidity estimated as in 3.1.4.2.2

3.4.2.2.3 Total, reducing and non-reducing sugars

Total, reducing and non-reducing sugars estimated as in 3.1.4.2.3

3.4.2.2.4 Ascorbic acid

Ascorbic acid estimated as in 3.1.4.2.4

3.4.2.3 Sensory evaluation

Sensory evaluation of fruit as in 3.1.4.3

3.5 Tabulation and statistical analysis

Observations under each experiment were tabulated and analyzed statistically in a completely randomized design (CRD) as proposed by Panse and Sukhatme (1976). The treatments were ranked according to Duncan's Multiple Range Test (DMRT) as suggested by Duncan (1955). Data pertaining to organoleptic evaluation were analysed using Kendall's coefficient of concordance.

RESULTS

4. RESULTS

The results of the studies conducted in the Department of Processing Technology, College of Horticulture during 2012-2013 under the project "Postharvest management studies in pineapple (*Ananas comosus* (L.) Merr.)" are presented in this chapter under the following headings.

4.1 Standardization of harvest method and stage of harvest in pineapple

4.2 Evaluation of storage method

4.3 Postharvest treatment studies

4.4 Optimization of storage temperature

4.1 Standardization of harvest method and stage of harvest in pineapple

Postharvest quality of any fruit depends on the correct maturity at the time of harvesting .The quality of fruits can also be ensured by adopting proper method of harvest. Standardization of maturity indices in pineapple can be done by assessing various physico-chemical changes taking place during the ripening process. Harvesting fruits at optimum maturity by appropriate method help to reduce the losses during postharvest handling, and maintain the quality of the produce when it reaches the consumer. Therefore, the present study was carried out to investigate the physico-chemical changes during different maturity stages for determining the optimum stage and method of harvesting in pineapple. Four stages of maturity like mature green, development of eye colour from 0-25%, 25-50% and 50-100% to yellow and two methods of harvesting (with and without peduncle) were carried out. The results are discussed here.

4.1.1 Physical parameters

4.1.1.1 Physiological loss in weight (%)

The physiological loss in weight (PLW) is regarded as an important parameter in determining fruit quality as the fresh produce continues to lose water after harvest causing loss of weight and finally resulting in shrinkage. It reduces the marketability of the fruit. In this experiment PLW was recorded cumulatively at three days interval in all the treatments. The treatments differed significantly with respect to PLW as given in Table 1.

The PLW was less for treatments from T_5 to T_8, wherein fruits were harvested with more than 25% of eyes changed to yellow and among these, in treatments T_5 and T_7, PLW was comparatively less when fruits were harvested by retaining 2cm of peduncle. During storage the PLW was significantly lowest in T_7 (6.22 %) and highest in T_2 (12.52%) after 9 days storage. After 12 days of storage lowest PLW (16.72 %) was observed in T_3.

The percentage loss was higher when the fruits were harvested at an early stage when eyes were still green during the entire period of storage. However, the fruits harvested at early stage had more shelf life.

4.1.1.2 Blackening /browning

The change of colour seen on the surface of fruit is taken as one of the negative character. There was no external change observed in any of the treatments up to 5 days of storage under ambient condition. On 6^{th} day of storage the fruits harvested at 50-100% eyes turned yellow stage started showing signs of external browning. All the treatments showed signs of external browning on 9^{th} day of storage in which the fruits harvested at late maturity stage (T_6, T_7 and T_8) showed maximum external browning. At the end of storage period fruits harvested when 0-25% eyes turned yellow by retaining peduncle (T_3) showed less browning compared to all other treatments.

4.1.1.3 Incidence of spoilage

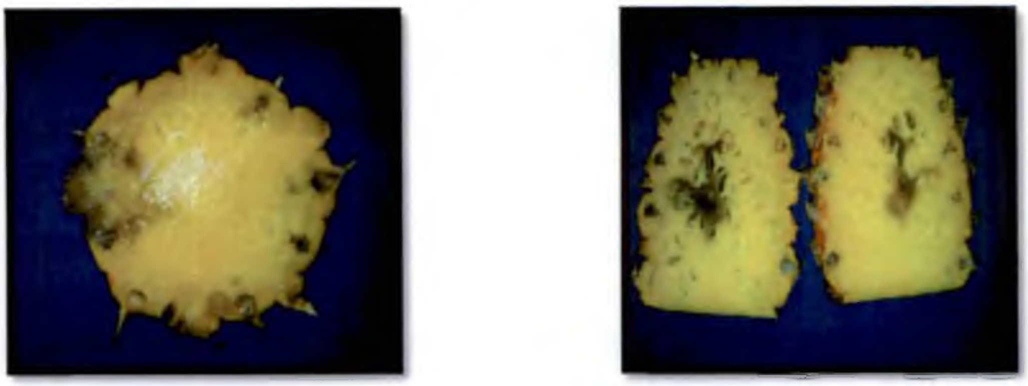
Spoilage of fruits is due to different factors like maturity at harvest, method of harvest and storage, attack by pathogens like bacteria, fungi and yeast. It was more in fruits harvested at advanced stages of ripening. Fruits harvested when 50-100% eyes changed to yellow spoiled faster than all other treatments. Also the fruits harvested by retaining peduncle showed less spoilage than the fruits harvested without peduncle. However, the fruits harvested at 0-25% eyes turned yellow with peduncle showed least spoilage (T_3).

4.1.1.4 Shelf life (days)

The shelf life was calculated as number of days till the fruit remained marketable. Unmarketability was attributed when more than 50 percent of fruits in a treatment showed spoilage.

Maximum shelf life of 13 days was recorded by T_3 (fruits harvested at 0-25% eyes turned yellow by retaining peduncle) and minimum (9 days) by T_8 (50-100% eyes changed to yellow without retaining peduncle).

External blackening



Internal spoilage

Plate 4. Fruit spoilage

Table 1. Effect of method and stage of harvest on PLW (%) and shelf life (days)

Treatments	PLW (%)					Shelf life (days)
	0DAS	3 DAS	6DAS	9DAS	12DAS	
T_1	0	4.35 ^{a}	5.83 ^{a}	11.75^{a}	18.73^{b}	12.0
T_2	0	4.58 ^{a}	6.16 ^{a}	12.52^{a}	20.22^{a}	11.3
T_3	0	2.51^{c}	3.35^{c}	9.47^{bc}	16.72^{c}	13.0
T_4	0	3.40 ^{b}	4.53 ^{b}	9.98^{b}	18.35^{b}	11.3
T_5	0	2.44^{c}	3.64^{bc}	8.21^{cd}	ND	10.3
T_6	0	2.98^{bc}	4.26^{bc}	8.86^{bcd}	ND	10.3
T_7	0	1.66^{d}	3.65^{bc}	6.22^{e}	ND	9.3
T_8	0	2.64^{bc}	4.39^{bc}	7.70^{d}	ND	9.0

ND- not determined due to termination of shelf life

Values with different alphabets as superscripts are significantly different

T_1 - Fruits harvested at fully mature green stage with peduncle.

T_2 - Fruits harvested at fully mature green stage without peduncle

T_3 - Fruits harvested when 0-25% eye colour changed to yellow with peduncle

T_4 - Fruits harvested when 0-25% eye colour changed to yellow without peduncle

T_5 - Fruits harvested when 25-50% eye colour changed to yellow with peduncle

T_6 - Fruits harvested when 25-50% eye colour changed to yellow without peduncle

T_7 - Fruits harvested when 50-100% eye colour changed to yellow with peduncle

T_8 - Fruits harvested when 50-100% eye colour changed to yellow without peduncle

4.1.2 Biochemical parameters

General analysis of variance for biochemical constituents like TSS, acidity, ascorbic acid, reducing, non- reducing and total sugars are given in Table 2a and 2b.

4.1.2.1 TSS (°brix)

TSS was found to increase during the course of storage in all the treatments. The treatments showed significant difference during the storage period and the highest value for TSS was recorded in T_7 (19.63°brix), followed by T_8 (19.43°brix) when the fruits were harvested at 50-100% colour break with and without peduncle respectively and similar trend was noticed even after two weeks of storage.

The lowest value of TSS was observed in treatment T_2 on the day of harvest (12.07°brix), and same trend was observed one week (13.50°brix) and two weeks (16.27°brix) of storage .It was on par with T_1, where in both the treatments, the fruits were harvested when they were green in colour.

At the same time highest percentage increase in TSS was observed one week after storage in treatment T_3 and two weeks of storage in treatment T_2 when the fruits were harvested at fully green stage.

4.1.2.2 Acidity (%)

In storage acidity showed a decreasing trend and the treatments were significantly different. The lowest value for acidity (0.39%, 0.34%, and 0.32%) during harvest, one and two weeks of storage respectively was observed in fruits harvested at 50-100% maturity with peduncle (T_7). Acidity was high when fruits were harvested in green mature stage and 0-25% eyes turned yellow and the treatments were on par.

4.1.2.3 Reducing, Non-reducing and Total sugar (%)

Significant variation was observed in reducing, non-reducing and total sugars among the treatments. Reducing, non-reducing and total sugars were highest when the fruits were harvested with 50-100% eye colour changed to yellow with and without peduncle (T_7) on the day of harvest as 4.23%, 9.52%, 13.75% respectively and it is on par with T_8.

Lowest values for reducing, non-reducing and total sugar were observed when fruits harvested at green colour stage as 3.68%, 8.44%, 12.12% respectively and it is on par with T_2.

Reducing sugar was found to decrease during the entire period of storage, whereas, non-reducing and total sugar first increased and then decreased during the course of storage.

4.1.2.4 Ascorbic acid (mg/100g)

With the advancement of storage period, a decline in the content of ascorbic acid was noticed in all the treatments. Significant difference between treatments was not observed during storage and it range from 8.33 to 15.28 mg/100g.

4.1.3 Sensory evaluation

In pineapple, colour, taste, flavour and texture contribute to the fruit quality. Hence for quality assessment, sensory evaluation was carried out on a nine point hedonic scale using score card for five attributes namely colour, taste, flavour, texture and overall acceptability. Each character was scored on the scale and the total scores calculated out of forty five. Sensory evaluation was conducted during first week and second week of storage. Observations are given in Table 3a and 3b.

The agreement regarding the scoring of judges on the various parameters like colour, taste, flavour, texture and overall acceptability for the pineapple fruits were analyzed using Kendall's coefficient of concordance (W). Kendall's W was found to be significant for all the parameters under observation (Appendix III). Hence the mean scores were taken to differentiate the acceptability of the products with regard to the characters.

During the first week of storage, among the eight treatments the highest score for colour and flavour was observed in T_7, for texture in T_3, for taste and overall acceptability in T_5 and lowest score by T_2. The highest total sensory score (40.39) was recorded when the fruits were harvested at 25-50% eyes changed to yellow retaining peduncle followed by T_6 (39.75) when the fruits were harvested in the same stage but without peduncle.

During 2nd week storage, maximum values for taste, flavour, texture and overall acceptability was recorded by T_3 (0-25% eyes changed to yellow by retaining peduncle). But the maximum value for colour was observed in T_5 (25-50% eyes changed to yellow by retaining peduncle). The highest total score (41.05) was recorded in T_3 (0-25% eyes changed to yellow by retaining peduncle).

Among the eight treatments, when the fruits were harvested at 0-25% eyes turned yellow by retaining peduncle (T_3) was having better shelf life and sensory qualities. Hence the fruits harvested at this stage were used for further storage studies.

Table 2a. Effect of method and stage of harvest on TSS, acidity and ascorbic acid content of fruits

Treatments	TSS (°brix)			Acidity (%)			Ascorbic acid (mg/100g)		
	Day of harvest	1^{st} week	2^{nd} week	Day of harvest	1^{st} week	2^{nd} week	Day of harvest	1^{st} week	2^{nd} week
T_1	12.33^{d}	13.63^{d}	16.33^{c}	0.66^{a}	0.55^{a}	0.49^{ab}	15.28^{a}	11.11^{a}	9.72^{a}
T_2	12.07^{d}	13.5^{d}	16.27^{c}	0.66^{a}	0.57^{a}	0.51^{a}	14.58^{ab}	11.11^{a}	10.42^{a}
T_3	14.07^{c}	16.3^{c}	18.37^{b}	0.59^{a}	0.49^{ab}	0.43^{c}	15.28^{a}	11.11^{a}	9.72^{a}
T_4	14.47^{c}	16.4^{c}	18.53^{b}	0.61^{a}	0.51^{a}	0.45^{bc}	13.19^{ab}	11.11^{a}	8.33^{a}
T_5	16.13^{b}	18.6^{b}	19.4^{a}	0.48^{b}	0.43^{bc}	0.35^{d}	13.19^{ab}	11.11^{a}	9.03^{a}
T_6	16.13^{b}	18.53^{b}	19.3^{a}	0.46^{bc}	0.41^{cd}	0.37^{d}	13.19^{ab}	11.11^{a}	10.42^{a}
T_7	18.03^{a}	19.47^{a}	19.63^{a}	0.39^{c}	0.34^{d}	0.32^{d}	13.19^{ab}	9.72^{a}	9.03^{a}
T_8	17.97^{a}	19.33^{a}	19.43^{a}	0.43^{bc}	0.37^{cd}	0.34^{d}	11.81^{b}	9.03^{a}	9.03^{a}

Values with different alphabets as superscripts are significantly different

Table 2b. Effect of method and stage of harvest on reducing, non-reducing and total sugar content of fruits

Treatments	Reducing sugar (%)			Non reducing sugar (%)			Total sugar (%)		
	Day of harvest	1^{st} week	2^{nd} week	Day of harvest	1^{st} week	2^{nd} week	Day of harvest	1^{st} week	2^{nd} week
T_1	3.68^{e}	3.6^{d}	3.57^{e}	8.44^{d}	8.78^{d}	8.42^{d}	12.12^{e}	12.38^{f}	11.99^{e}
T_2	3.68^{e}	3.59^{d}	3.56^{e}	8.43^{d}	8.81^{d}	8.39^{d}	12.11^{e}	12.41^{f}	11.98^{e}
T_3	3.94^{d}	3.85^{c}	3.73^{cd}	8.67^{c}	8.99^{c}	8.66^{c}	12.61^{d}	12.85^{e}	12.39^{d}
T_4	3.93^{d}	3.83^{c}	3.70^{d}	8.7^{c}	9.05^{c}	8.67^{c}	12.63^{d}	12.87^{e}	12.38^{d}
T_5	4.03^{cd}	3.91^{bc}	3.78^{bcd}	9.00^{b}	9.33^{b}	8.95^{b}	13.03^{c}	13.24^{d}	12.73^{c}
T_6	4.1^{bc}	3.96^{ab}	3.84^{abc}	9.06^{b}	9.39^{b}	9.02^{b}	13.16^{b}	13.34^{c}	12.85^{b}
T_7	4.23^{a}	4.03^{a}	3.94^{a}	9.52^{a}	9.86^{a}	9.42^{a}	13.75^{a}	13.89^{a}	13.36^{a}
T_8	4.17^{ab}	3.97^{ab}	3.87^{ab}	9.49^{a}	9.82^{a}	9.46^{a}	13.66^{a}	13.78^{b}	13.32^{a}

Values with different alphabets as superscripts are significantly different

Table 3a. Effect of method and stage of harvest on sensory attributes of fruit during 1st week of storage

Treatment	Colour	Taste	Flavour	Texture	Overall acceptability	Total score
T_1	5.73	7.43	6.75	7.11	5.39	32.40
T_2	5.56	7.17	6.60	7.51	4.85	31.68
T_3	7.13	7.57	7.49	8.04	6.99	37.22
T_4	6.79	7.40	7.20	7.75	6.45	35.59
T_5	7.55	8.53	8.13	8.04	8.13	40.39
T_6	7.51	8.33	7.95	7.91	8.04	39.75
T_7	8.10	8.04	8.17	7.39	7.22	38.93
T_8	7.60	7.65	7.97	7.26	7.04	37.53

Table 3b. Effect of method and stage of harvest on sensory attributes of fruit during 2nd week of storage

Treatment	Colour	Taste	Flavour	Texture	Overall acceptability	Total score
T_1	7.27	7.93	7.71	8.00	7.39	38.29
T_2	7.44	7.75	7.41	7.77	7.35	37.73
T_3	8.02	8.63	8.26	8.11	8.04	41.05
T_4	7.95	8.40	8.07	7.99	7.62	40.03
T_5	8.13	7.99	8.26	7.08	7.04	38.49
T_6	8.06	7.75	8.26	7.00	6.93	38.00
T_7	7.73	7.17	7.09	6.42	5.33	33.74
T_8	7.69	6.91	6.78	5.99	4.98	32.36

4.2 Evaluation of storage method

The common practice among the farmers is to bring the fruits to the market fresh from the field, stack and cover with silpaulin for auction and transportation to distant markets. Hence four different methods of storage like heaping and covering with silpaulin (150 GSM), stacking fruits vertically with crown downwards, stacking fruits vertically with crown upwards and storing in paper cartons were evaluated and presented here. Pineapple fruits harvested when 0-25% eyes of the fruits changed to yellow by retaining peduncle is used for evaluation of the storage method. Physical and biochemical parameters were studied and presented here.

4.2.1 Physical parameters

4.2.1.1 Physiological loss in weight (%)

The PLW was recorded cumulatively at three days interval in all the treatments. There was no significant difference observed for PLW at 6^{th} and 9^{th} day of storage (Table 4).

However when the fruits were stacked vertically with crown downward showed minimum PLW on 9^{th} day of storage and it could be stored for more than 12 days . The maximum PLW was observed when the fruits were heaped and covered with silpaulin (T_1).

On 12^{th} day of storage only two treatments were available for estimating PLW as other treatments were discarded due to spoilage. Minimum PLW was registered by T_2 (17.16%) and maximum by T_3 (17.51%).

4.2.1.2 Blackening /browning (external changes)

The maximum amount of blackening /browning was found in T_1 (fruits heaped and covered with silpaulin) followed by T_4 (fruits stored in paper cartons) and minimum blackening was found in T_2 (fruits stacked vertically with crown downwards).

There was incidence of peduncle damage for T_3 (fruits stacked vertically with crown upwards).

Table 4. Effect of storage method on PLW (%) and shelf life (days)

Treatments	PLW (%)					Shelf life (days)
	0DAS	3 DAS	6DAS	9DAS	12DAS	
T_1	0	2.79^{ab}	3.72^{a}	10.18^{a}	ND	9.0
T_2	0	2.37^{b}	3.53^{a}	9.33^{a}	17.16^{a}	13.0
T_3	0	2.57^{ab}	3.45^{a}	9.69^{a}	17.51^{a}	12.0
T_4	0	2.88^{a}	3.53^{a}	9.85^{a}	ND	10.0

Values with different alphabets as superscripts are significantly different

ND - Not determined due to termination of shelf life

T_1- Heaping and covering with silpaulin (150 GSM)

T_2- Stacking fruits vertically with crown downward

T_3- Stacking fruits vertically with crown upward

T_4- Storing fruits in paper cartons of standard size

4.2.1.3 Incidence of spoilage

Spoilage of fruits was observed as external browning, formation of watery spots, fermentation and decay. The fruits stored under tarpaulin showed symptoms of damage from 3rd day onwards and symptoms of damage was observed on 6th day by fruits stored in cartons. Spoilage was observed only on 9th day in fruits stored by stacking vertically with crown downwards.

4.2.1.4 Shelf life (days)

The shelf life was calculated as number of days till the fruit remained marketable. Unmarketability was attributed when more than 50 percent of fruits in a treatment showed spoilage.

Maximum shelf life was recorded by the treatment T_2 (fruits stacked vertically with crown down) as 13 days and minimum by T_1 (fruits covered with 150 GSM silpaulin) as 9 days.

4.2.2 Biochemical parameters

General analysis of variance for biochemical constituents like TSS, acidity, ascorbic acid, reducing, non- reducing and total sugars are given in Table 5a and 5b.

4.2.2.1 TSS (°brix)

There was no significant difference between treatments in TSS. During the 1st week it ranged 16.1 to 16.6°brix. However, the highest TSS was observed for T_2 (18.17°brix) and lowest for T_1 (17.77°brix) at the end of the storage. At the same time the percentage increase in TSS was found to be significantly different and the highest value was observed in treatment T_2 after storage.

4.2.2.2 Acidity (%)

There was no significant difference in acidity during 1st week of storage. Significant difference was observed during 2nd week of storage. The lowest value for acidity was observed in T_3 (0.36%) and highest in T_1 (0.48%) in 2nd week of storage. The percentage decrease in acidity was highest for T_2 after storage.

4.2.2.3 Reducing, Non-reducing and Total sugar (%)

Significant difference was observed for reducing, non-reducing and total sugar during storage. Highest amount of reducing and total sugar was observed in treatment T_2 as 3.76 percent and 12.44 percent respectively during 2nd week of storage and it was on par with T_3. During 2nd week of storage the treatment T_1 showed lowest reducing (3.67%) and total sugar (12.23%). The percentage decrease in reducing and total sugar was lowest for T_2.

Among the treatments non-reducing sugar was highest in treatment T_3 (8.68%) during 2nd week of storage, and T_2 was on par with it.

4.2.2.4 Ascorbic acid (mg/100g)

There was no significant difference between the treatments for ascorbic acid content. However, the highest value was observed in T_3 (10.41 mg/100g) in 2nd week storage.

Table 5a. Effect of storage methods on TSS, acidity and ascorbic acid content of fruits

Treatments	TSS (°brix)		Acidity (%)		Ascorbic acid (mg/100g)	
	1st week	2nd week	1st week	2nd week	1st week	2nd week
T_1	16.55^{a}	17.77^{a}	0.53^{a}	0.48^{a}	11.98^{a}	9.37^{a}
T_2	16.23^{ab}	18.17^{a}	0.48^{a}	0.37^{b}	12.5^{a}	9.89^{a}
T_3	16.1^{b}	17.95^{a}	0.46^{a}	0.36^{b}	12.5^{a}	10.41^{a}
T_4	16.6^{a}	18.05^{a}	0.48^{a}	0.41^{ab}	11.45^{a}	8.85^{a}

Values with different alphabets as superscripts are significantly different

Table 5b. Effect of storage methods on reducing, non-reducing and total sugar content of fruits

Treatments	Reducing sugar (%)		Non –reducing sugar (%)		Total sugar (%)	
	1st week	2nd week	1st week	2nd week	1st week	2nd week
T_1	3.83^{b}	3.67^{c}	9.23^{b}	8.57^{b}	13.05^{b}	12.23^{c}
T_2	3.87^{a}	3.76^{a}	9.06^{c}	8.68^{a}	12.93^{c}	12.44^{a}
T_3	3.87^{a}	3.73^{ab}	9.05^{c}	8.69^{a}	12.92^{c}	12.42^{a}
T_4	3.81^{c}	3.68^{bc}	9.31^{a}	8.65^{a}	13.12^{a}	12.34^{b}

Values with different alphabets as superscripts are significantly different

T_1-Heaping and covering with silpaulin (150 GSM)

T_2- Stacking fruits vertically with crown downward

T_3- Stacking fruits vertically with crown upward

T_4- Storing fruits in paper cartons of standard size

4.2.3 Sensory evaluation

Sensory evaluation was carried out on a nine point hedonic scale using score card for five attributes namely colour, taste, flavour, texture and overall acceptability. Each character was scored on the scale and the total scores calculated out of forty five. Sensory evaluation was conducted 1 week and 2 weeks of storage. Observations are given in Table 6a and b.

Kendall's W was found to be significant for colour and overall acceptability during first week of storage and for taste, flavour, texture and overall acceptability during second week storage under observation (Appendix IV). Hence the mean scores were taken to differentiate the acceptability of the products with regard to the characters.

During first week of storage, among the four treatments highest total sensory score (41.15) was recorded in T_4 (fruits stored in paper cartons). Maximum score for colour and overall acceptability was observed in T_4 and minimum score for colour and overall acceptability was noted in T_3 and T_1 respectively.

In second week of storage, the highest total score (40.65) was recorded when fruits stacked vertically with crown downward (T_2) and least (33.42) in T_1 (fruits heaped and covered with silpaulin). Maximum score for taste, texture and overall acceptance was noted in T_2 whereas flavour in T_3.

Among the different methods of storage longest shelf life, highest TSS, sugar and better sensory quality was noticed in T_2 (stacking fruits vertically with crown downwards) and was used for further studies.

Table 6a. Effect of storage methods on sensory attributes of fruit during 1st week of storage

Treatments	Colour	Taste	Flavour	Texture	Overall acceptability	Total score
T_1	7.72	7.95	7.91	7.73	7.44	38.76
T_2	7.50	8.01	8.05	8.05	8.11	39.73
T_3	7.35	8.00	8.03	8.04	8.07	39.49
T_4	8.03	8.49	8.46	7.94	8.22	41.15

Table 6b. Effect of storage methods on sensory attributes of fruit during 2nd week of storage

Treatments	Colour	Taste	Flavour	Texture	Overall acceptability	Total score
T_1	7.77	7.22	7.63	5.22	5.59	33.42
T_2	7.96	8.57	8.26	7.48	8.38	40.65
T_3	7.93	8.35	8.35	7.29	8.15	40.05
T_4	8.07	8.24	8.01	6.22	7.07	37.62

4.3 Post-harvest treatment studies

Postharvest treatments like immersing in cold water, 1% acetic acid, luke warm chlorinated water, alum and hot water dip were given to prolong storage period without loss of quality. The effect of the treatments on PLW, microbial load and shelf life were studied and the results are discussed below.

4.3.1 Physiological loss in weight (%)

The PLW was recorded cumulatively at three days interval in all the treatments. The treatments differed significantly with respect to PLW as given in Table 7.

Minimum value for PLW (23.23%) was recorded when fruits were given hot water dip treatment (T_5) during storage, whereas highest loss in physiological weight (32.87%) was recorded when fruits were stored without any postharvest treatments (T_6) and it was significantly different from all the treatments during entire period of storage.

4.3.2 Total microbial load

The total microbial load before and after post-harvest treatments were estimated (Table 8). The microbial load differed significantly for all the treatments. The initial bacteria and fungi load before postharvest treatments were 17.38×10^6 CFU/ml and 2.68×10^3 CFU/ml respectively and there was no yeast population. But the microbial count increased during the storage.

During storage, minimum bacterial count (4.85×10^6 CFU/ml) and fungal count (1.83×10^3 CFU/ml) was noticed in T_5 (hot water dip treatment) followed by T_4 (immersing in 1000ppm alum) and maximum in T_6 (control). During first week of storage presence of yeast was not detected, but after 2 weeks yeast presence was observed and lowest count (2.53×10^3 CFU/ml) was in T_5 followed by T_4 (2.98×10^3 CFU/ml). The highest count was noticed in T_6 (5.63×10^3 CFU/ml).

4.3.3 Shelf life (days)

The shelf life was calculated as number of days till the fruit remained marketable. Unmarketability was attributed when more than 50 percent of fruits in a treatment showed spoilage.

Maximum shelf life was recorded by T_5 (fruits treated by hot water dip) as 14.5 days and minimum by T_6 (control) as 13 days.

Among the treatments the least PLW, microbial load and longest postharvest life was noticed in fruits treated by hot water dip (T_5) and was used for storage temperature studies.

Table 7. Effect of postharvest treatment on PLW (%) and shelf life (days)

Treatments	PLW (%)					Shelf life (days)
	0DAS	3 DAS	6DAS	9DAS	12DAS	
T_1	0	4.97^c	10.42^c	14.67^d	24.33^d	13.3
T_2	0	7.45^b	12.54^b	20.79^b	30.66^b	13.5
T_3	0	5.24^c	9.52^{cd}	14.75^d	24.22^d	14.0
T_4	0	6.91^b	11.7^b	18.08^c	26.89^c	14.0
T_5	0	4.93^c	9.31^d	14.48^d	23.23^e	14.5
T_6	0	9.79^a	15.17^a	23.54^a	32.87^a	13.0

Values with different alphabets as superscripts are significantly different

T_1 –Immersing fruits in cold water for 10 min

T_2 – Immersing fruits in 1% acetic acid for 10 min

T_3 – Immersing fruits in luke warm chlorinated water (100ppm) for 10 min.

T_4 – Immersing fruits in alum (1000 ppm) for 10 min.

T_5 – Hot water dip treatment (50°C) for 1 min

T_6 – Control

Table 8. Microbial load before and after postharvest treatments

Before treatment (T_0)			**Treatments**	**1 week after storage**			**2 week after storage**		
Bacteria ($x10^6$ CFU/ml)	Fungus($x10^3$ CFU/ml)	Yeast($x10^3$ CFU/ml)		Bacteria ($x10^6$ CFU/ml)	Fungus($x10^3$ CFU/ml)	Yeast($x10^3$ CFU/ml)	Bacteria ($x10^6$ CFU/ml)	Fungus($x10^3$ CFU/ml)	Yeast($x10^3$ CFU/ml)
			T_1	17.93^{b}	6.05^{ab}	0	23.33^{b}	7.88^{a}	5.30^{a}
			T_2	9.35^{c}	5.55^{bc}	0	25.55^{b}	6.88^{b}	3.83^{b}
			T_3	9.23^{c}	5.05^{cd}	0	15.28^{c}	6.38^{b}	3.73^{b}
17.38	2.68	0	T_4	6.68^{d}	4.48^{d}	0	12.35^{d}	6.23^{b}	2.98^{c}
			T_5	4.85^{d}	1.83^{e}	0	10.78^{d}	3.63^{c}	2.53^{c}
			T_6	25.00^{a}	6.48^{a}	0	30.28^{a}	8.48^{a}	5.63^{a}

Values with different alphabets as superscripts are significantly different

T_1 T_2 T_3

T_4 T_5 T_6

Plate 5. Effect of postharvest treatments on visual quality of fruits

4.4. Optimization of storage temperature

Temperature is an important environmental factor affecting postharvest life of fruits and vegetables. Low temperature storage is an effective means for keeping horticultural commodities at high post-harvest quality. Therefore, investigations were done to optimize storage temperature for extending the shelf life of pineapple without adversely affecting quality. The results of the study are discussed below.

4.4.1 Physical parameters

4.4.1.1 Physiological Loss in Weight (%)

The PLW was recorded cumulatively at three days interval in all the treatments. The treatments differed significantly. Observations are given in Table 9a and 9b.

Up to 18 days of storage minimum PLW was observed for T_2 (fruits stored at 8±2°C) and maximum for T_1 (fruits stored at ambient condition). However during the end of storage, minimum PLW was recorded for T_2 as 32.19%.

4.4.1.2 Blackening /browning

Internal browning is a disorder found when fruits are stored at low temperature. The fruits looked externally fresh, but when cut open internal browning was noticed. When the fruits were stored at 14±2°C, 20±2°C and 24±2°C internal browning was noticed where as it was less in T_2 (8±2°C). The symptoms of yellowing in the crowns were more prevalent in the fruits stored at 24±2°C. The fruits stored at ambient condition (T_1) showed external discolorations without internal browning.

4.4.1.3 Incidence of spoilage

The fruits stored at ambient condition showed more spoilage compared to other treatments. At low temperature spoilage is negligible except for the internal browning.

Table 9a. Effect of storage temperature on PLW (%) and shelf life (days)

Treatments	PLW (%)							Shelf life (days)
	0DAS	3DAS	6DAS	9DAS	12DAS	15DAS	18 DAS	
T1	0	7.59[a]	13.61[a]	18.59[a]	22.46[a]	ND	ND	14.5
T2	0	1.66c	3.29[c]	5.91[c]	9.45[c]	13.16[c]	16.79[c]	33
T3	0	2.22[c]	4.40[c]	8.17[c]	11.16[d]	15.19[b]	19.56[b]	26.5
T4	0	1.97[c]	3.94[c]	9.26[c]	13.20[c]	16.06[b]	20.92[a]	20
T5	0	3.67[b]	9.47[b]	15.06[b]	20.86[b]	22.85[a]	ND	17

Values with different alphabets as superscripts are significantly different

Table 9b. Effect of storage temperature on PLW (%) [21-27 DAS]

Treatments	21 DAS	24 DAS	27 DAS
T2	21.98	28.31	32.19
T3	24.52	30.38	35.11
T value	2.207	2.488	4.202

4.4.1.1 Shelf life (days)

Maximum shelf life was recorded by the treatment T_2 (cold storage at 8±2°C) as 33 days and minimum by T_1 (ambient condition) as 14.5days. After 20 days of storage fruits stored at 14±2°C, 20±2°C and 24±2°C were discarded.

4.4.2 Biochemical parameters

General analysis of variance for biochemical constituents like TSS, acidity, ascorbic acid, reducing, non- reducing and total sugars are given in Table 10a and 10b.

4.4.2.1 TSS (°brix)

During cold storage, TSS was found to increase during the initial period and then decreased during course of storage. The treatments showed significant difference during the first two weeks of storage period, whereas significance was not observed during 3rd and 4th week of storage. The highest value for TSS was recorded in treatment T_2 during the entire course of storage and it ranged from 17 to 18.3°brix.

4.4.2.2 Acidity (%)

Significance was observed for acidity for the first two weeks of storage. In case of acidity there was a decreasing trend in all the treatments during initial period of storage and then an increasing trend was observed. The lowest value for acidity was observed in T_1 (0.44%) during first 2 weeks and in T_3 after 2 week storage. The highest value for acidity was observed in T_2 during the entire course of storage.

4.4.2.3 Reducing, Non-reducing and Total sugar (%)

Reducing, Non-reducing and Total sugars were found to decrease during the storage period in all treatments. Significant difference for reducing sugar was noted for 4th week only and significance for non-reducing sugar was noted for 2nd week only. In case of total sugar the treatments were not significant during entire period of storage.

T_1

T_2

T_3

T_4

T_5

Plate 6. Effect of storage temperature on fruit quality during storage

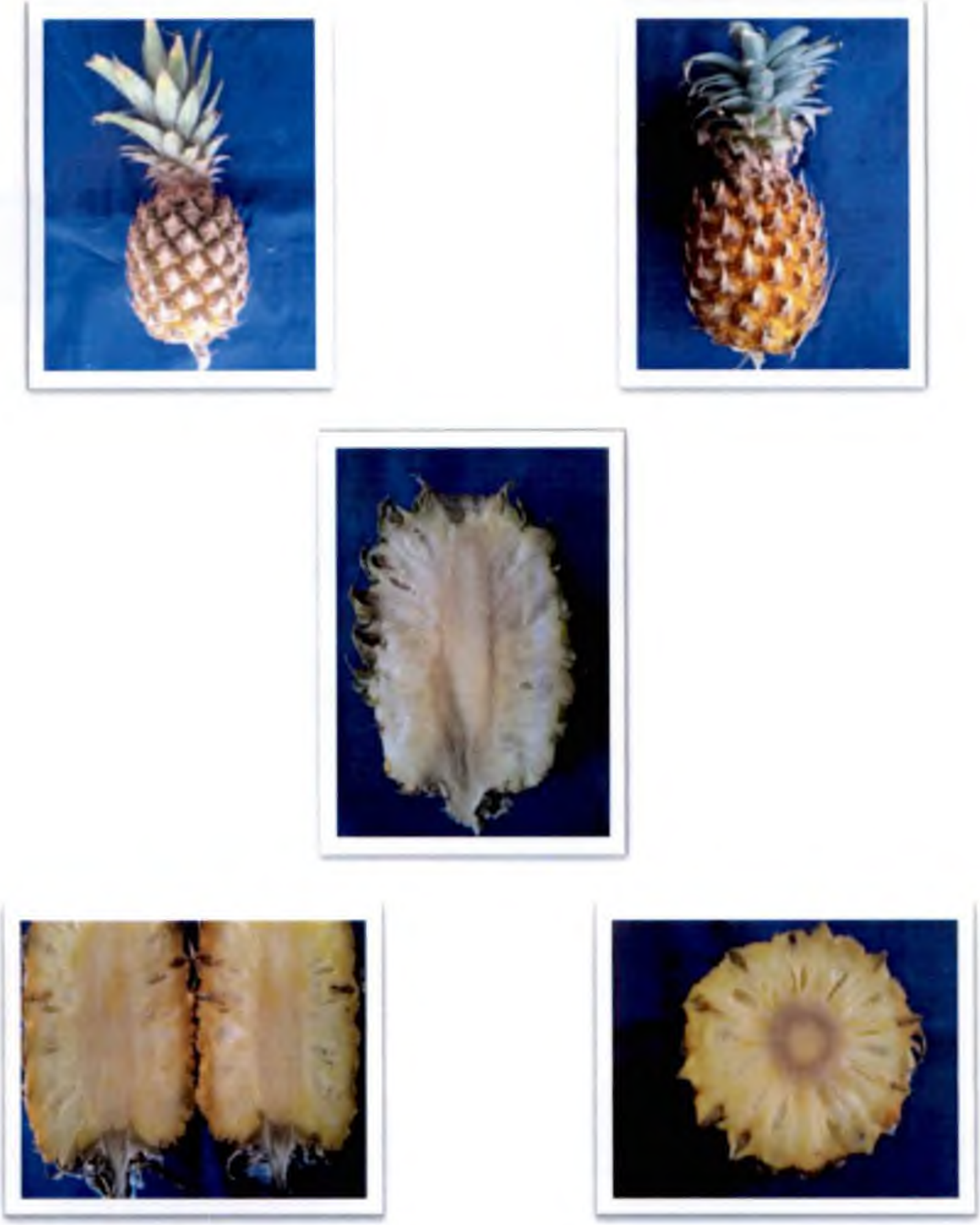


Plate 7. Fruit spoilage in low temperature storage

4.4.2.4 Ascorbic acid (mg/100g)

Significant variation between treatments was recorded in ascorbic acid content during entire storage period. With the advancement of storage period, a decline in the content of ascorbic acid was noticed in all the treatments. Highest ascorbic acid was observed in T_2 during entire period of storage and it ranged from 14.06 to 19.79 mg/100g.

4.4.3 Sensory evaluation

Sensory evaluation was carried out on a nine point hedonic scale using score card for five attributes namely colour, taste, flavour, texture and overall acceptability. Each character was scored on the scale and the total scores calculated out of forty five. Sensory evaluations were observed for 1, 2, 3 and 4 week after storage. Observations are given in Table 11a,11b,11c and 11d.

Kendall's W was found to be significant for all the parameters under observation on first, second and fourth week of storage (Appendix V). During third week Kendall's W was found to be significant for taste and overall acceptability only. Hence the mean scores were taken to differentiate the acceptability of the products with regard to the characters.

During the first and second week of storage, among the five treatments highest total sensory score was recorded in T_2 (cold storage: 8± 2 ^{0}C) as 41.13 and least in T_1 (ambient condition) as 36.97. Mean scores for all the characters like colour, taste, flavour and texture was highest in T_2 and lowest in T_1.

Sensory evaluation in third and fourth week storage was done for two treatments only as the treatment T_1, T_4 and T_5, were discarded due to spoilage. Among the two treatments highest total sensory score was recorded in T_2.

Among the treatments maximum shelf life, highest TSS and ascorbic acid content and better sensory quality were observed in T_2 (cold storage: 8± 2 ^{0}C).

Table 10a. Effect of storage temperature on biochemical constituents of fruits (1st and 2nd week of storage)

Treatments	TSS (°brix)		Acidity (%)		Ascorbic acid (mg/100g)		Reducing sugar (%)		Non-reducing sugar (%)		Total sugar (%)	
	1st week	2ndweek	1st week	2ndweek	1st week	2ndweek	1stweek	2ndweek	1stweek	2ndweek	1stweek	2ndweek
T_1	16.38^{c}	17.93^{b}	0.52^{c}	0.44^{c}	11.46^{c}	9.89^{b}	3.77^{a}	3.67^{a}	8.99^{a}	8.77^{b}	12.76^{a}	12.44^{a}
T_2	17.00^{a}	18.30^{a}	0.72^{a}	0.68^{a}	19.79^{a}	17.19^{a}	3.74^{a}	3.63^{a}	8.96^{a}	8.86^{a}	12.69^{a}	12.49^{a}
T_3	16.83^{ab}	17.95^{b}	0.68^{ab}	0.64^{a}	14.58^{b}	11.46^{b}	3.78^{a}	3.66^{a}	8.96^{a}	8.84^{ab}	12.74^{a}	12.49^{a}
T_4	16.65^{abc}	17.78^{b}	0.72^{a}	0.65^{a}	14.06^{b}	11.97^{b}	3.74^{a}	3.63^{a}	8.97^{a}	8.83^{ab}	12.74^{a}	12.44^{a}
T_5	16.50^{bc}	17.73^{b}	0.64^{b}	0.57^{b}	12.49^{bc}	11.46^{b}	3.74^{a}	3.64^{a}	8.89^{a}	8.71^{c}	12.75^{a}	12.49^{a}

Values with different alphabets as superscripts are significantly different

Table 10.b. Effect of storage temperature on biochemical constituents of fruits (3rd and 4th week of storage)

Treatments	TSS (°brix)		Acidity (%)		Ascorbic acid (mg/100g)		Reducing sugar (%)		Non-reducing sugar (%)		Total sugar (%)	
	3rdweek	4thweek	3rdweek	4thweek	3rdweek	4thweek	3rdweek	4thweek	3rdweek	4thweek	3rdweek	4thweek
T_2	17.5	17.23	0.77	0.85	15.63	14.06	3.63	3.55	8.63	8.38	12.26	11.92
T_3	17.45	17.1	0.72	0.78	10.94	10.42	3.66	3.60	8.59	8.37	12.25	11.97
T value	0.447	1.321	2.449	1.957	5.897	3.653	1.457	3.508	1.318	0.594	0.479	1.686

Table 11a. Effect of storage temperature on sensory qualities of fruit during 1st week of storage

Treatment	Colour	Taste	Flavour	Texture	Overall acceptability	Total score
T_1	7.01	7.52	7.45	7.83	7.15	36.97
T_2	7.95	8.14	8.02	8.53	8.50	41.13
T_3	7.55	7.87	7.88	8.40	8.24	39.94
T_4	7.37	7.83	7.75	8.04	8.01	39.00
T_5	7.21	7.65	7.62	7.90	7.82	38.2

Table 11b. Effect of storage temperature on sensory qualities of fruit during 2nd week of storage

Treatment	Colour	Taste	Flavour	Texture	Overall acceptability	Total score
T_1	8.01	7.65	7.77	8.17	7.97	39.57
T_2	8.29	8.30	8.19	8.70	8.49	41.97
T_3	8.09	8.10	8.20	8.45	8.24	41.08
T_4	8.02	8.00	8.02	8.27	8.14	40.45
T_5	8.01	7.80	7.87	8.19	7.98	39.85

Table 11c. Effect of storage temperature on sensory qualities of fruit during 3rd week of storage

Treatment	Colour	Taste	Flavour	Texture	Overall acceptability	Total score
T_2	8.30	7.39	7.93	8.71	8.18	40.51
T_3	8.18	7.16	7.92	8.55	7.89	39.70

Table 11d. Effect of storage temperature on sensory qualities of fruit during 4th week of storage

Treatment	Colour	Taste	Flavour	Texture	Overall acceptability	Total score
T_2	7.73	6.84	7.71	8.57	7.41	38.26
T_3	7.21	6.54	7.03	7.01	6.71	34.50

DISCUSSION

5. DISCUSSION

Pineapple is one of the delicious tropical fruits and in terms of worldwide production, it is currently the third most important fruit after banana and mango (FAO, 2008). However, due to high moisture content and active metabolism, deterioration of the fruit occurs soon after the harvest (Netto *et al.*, 2005).

Lack of proper storage facilities, improper handling, long distance transport and microbial spoilage owing to high temperatures in the country are the factors pre-disposing the fruits to damage. Due to the high perishability of the fruit, it is necessary to use proper postharvest techniques for maintaining quality during storage and handling. Hence the present study was taken up for identifying the optimum stage and method of harvest, postharvest treatments and storage methods for pineapple.

5.1 Standardization of harvest method and stage of harvest in pineapple

Fruit maturity and method of harvest are the most important factors affecting the quality and perishability of the fruit. In pineapple extent of eye flatness and colour development are considered to be the external indices for maturity. The biochemical parameters are also related to these maturity indices. Therefore, investigations were undertaken to standardize the harvest method and stage of harvest in pineapple and the results are discussed in this section.

Pineapple is a non- climacteric fruit, but the peel shows climacteric behaviour due to the increase in peel colour after harvesting (Rohana *et al.*, 2009).In the present study also there was an increase in peel colour during the storage period. The peel colour increases to yellow from the base of the peduncle to the crown. The colour change was faster in fruits harvested at late maturity stage, this was obvious in the case when fruits with more than fifty percent of eyes changed to yellow, attained maximum peel colour. Similar result was observed by Wijesinghe and Sarananda. (2002) in pineapple var. Mauritius. They found that the climacteric nature of pineapple peel may be not efficient to improve the peel colour in immature harvested fruit compared to that in mature stages. A decrease in shell chlorophyll and an increase in carotenoid content occur in harvested fruit (Singh, 2012). Various physical and biochemical changes during storage in the fruits harvested at different maturity stages are discussed below.

5.1.1 Physical parameters

Physical parameters like physiological loss in weight, blackening/browning, incidence of spoilage and shelf life were observed from the day of harvest till the fruits became unmarketable.

5.1.1.1 Physiological loss in weight

PLW is due to the loss of water by transpiration, evaporation and respiration. After harvesting the produce continues to lose water and it can no longer replace the lost water. This causes vapour pressure deficit and plant tissues shrink posing a serious problem in marketing. It begins to wilt and becomes unusable. It is an important parameter affecting the marketability of fruit. (Kumar *et al.*, 2009). Siddique *et al.*, 1991 also reported that the PLW in storage of guava fruit is due to evapo-transpiration and respiration. According to Dhar *et al.*, (2008) higher weight loss is probably due to high rate of dehydration through a particular mechanism. The moisture and subsequent weight loss in fruits of apple increased linearly with increase in storage duration due to water loss and respiration (Gafir *et al.*, 2009). In the present study, PLW showed significant difference between the treatments. The loss in weight was significantly lower when the fruits with peduncle were harvested with more than 25% of eyes yellow in colour. Similar results were observed by (Smith and Whiting, 2011) in sweet cherry cultivar 'Bing' , where the weight loss for stemmed fruits were significantly less than the stem less fruits. Higher PLW during storage was observed when fruits were harvested at early stages of maturity, indicating high rate of metabolic processes like respiration and transpiration.

5.1.1.2 Blackening/browning

Consumers judge the fruit quality by skin colour. Browning and further blackening are considered as the negative characters in judging the quality. Another universal problem noticed in fresh fruit was black rot characterized by soft water rot (Paull, 1997). The severity of the problem is dependent on the degree of bruising or wounding during harvesting and packaging, level of inoculum on the fruit and storage temperature during transportation and marketing (Rohrbach and Schmitt, 1994). Symptoms begin as a soft, watery rot which later darkens due to growth of the dark coloured fungus *Chalara paradoxa* (DeSeynes) Sacc. The soft texture of the fruits harvested at the later stages of maturity might have predisposed the fruits to bruising and black rot.

Fruits harvested at early stages of maturity with less eye colour showed least blackening. Whereas at later stages of maturity when more than fifty percent of eyes turned yellow, the quality deterioration was faster. At this stage, there are chances for the resident yeast to grow leading to fermentation thus making the skin surface brown and leathery and fruit become more spongy with bright yellow flesh (Paull and Chen, 2000).

5.1.1.3 Incidence of spoilage

In pineapple fruits the main reasons for damage are bruising during harvesting, injuries causing impact on the fruits and disease occurrence. Damaged areas are more susceptible to diseases. Diseased tissue turns dark brown and fruit tissue will be having a characteristic soft rot watery appearance (Rohrbach, 1983). Spoilage was severe in fruits harvested at late stages of maturity. There was presence of external mould growth. This may be due to high sugar content in the more ripened fruits. The increase in spoilage with the advancement of storage period may be attributed to progressive decrease in fruit firmness due to hydrolysis of metabolites when the fruits were stored for a longer period (Navjot *et al.*, 2009). However the fruits harvested by retaining peduncle showed less spoilage. Mootoo and Henry, (1995) opined that the base of snapped fruits may be a possible site of pathological infection. According to Haque and Dhua (1993), mango fruits harvested with stalks were less susceptible to storage decay than fruits harvested without stalks and had higher fruit quality during storage. Wijesinghe and Sarananda (2002) reported that entry of pathogenic fungi from the fruit base was not possible when the fruit stalk is retained in the harvested fruit.

5.1.1.4 Shelf life

Pineapple fruits must have desirable size and shape with good shell colour and flat eyes. The crown leaves should look fresh and should have a deep green colour. Negative characters include dull yellow skin appearance, presence of mould on the surface, fruits with an unfirm feel (Paull and Chen, 2000). Long shelf life is a desirable attribute, especially in storage, handling and marketing of fruits. Shelf life was found to be longest (13 days) for the fruits harvested at 0-25% eyes changed to yellow. According to Pantastico, 1975, pineapple with slightly yellow to one-half yellow surface had better shelf life than those with more surface colour, and fruit with no yellowing may not be mature enough for optimum eating quality. Fruits harvested at late stage of maturity had less shelf life (9 days) due to over maturation and rapid senescence. Similar findings were reported by Wijesinghe and Sarananda, 2002.

5.1.2 Chemical constituents

Chemical constituents like TSS, acidity, ascorbic acid and sugars were assessed at the day of harvest, one and two weeks after storage. Although pineapple is a non- climacteric fruit, there were significant changes in chemical constituents during storage. There was an increase in TSS and sugar content. Titrable acidity and ascorbic acid reduced during storage. The titrable acidity usually declines during storage of harvested pineapple and on the other hand, the sugar content of pineapple keeps increasing after harvest. (Paull, 1993).Reduction in acid and increase sugar content make pineapple after harvest sweeter and less sour. Nadzirah *et al.* (2013) found that the peel colour had a linear relationship with TSS as indicated by the increasing trend of TSS and peel colour with the storage period.

5.1.2.1 TSS

TSS is an important quality factor for many fresh fruits because solids include the soluble sugars, glucose and fructose as well as acids (Tehrani *et al.*, 2011). There is an increasing trend in TSS for all the treatments (Fig.1). Increase in TSS with increasing maturity was also noticed. Similar result was reported by Wijesinghe and Sarananda (2002). They reported that increase in TSS may be due to sugar synthesis during ripening or moisture loss during storage increasing the sugar concentration available in the fruit. TSS was highest (19.63° brix) for fruits harvested at late maturity stage than those harvested at early maturity stage (16.27° brix) after 2 weeks of storage.

5.1.2.2 Acidity

The titrable acidity showed significant difference for the treatments. The two major organic acids in pineapple are citric and malic acid. Acidity was found to decrease during the storage period (Fig.2). It was found to decrease with advancement of maturation process. At the end of storage, acidity was found to be least (0.32%) in fruits harvested at late maturity stage and highest (0.51%) in fruits harvested at early maturity stage. The decline in acidity during storage might account for use of organic acids in respiratory process (Ulrich, 1974; Lee *at al.*, 2010).The changes in titrable acidity are significantly affected by the rate of metabolism (Clarke *et al.*, 2003) especially respiration, which consumed organic acid and thus decline acidity during storage (Gafir *et al.*, 2009). Othman (2011) also reported that decrease in acidity during the ripening of pineapple was due to the loss in the dominant citric acid.

5.1.2.3 Ascorbic acid

Ascorbic acid showed a decreasing trend during storage, however significant variation was not observed. Soule and Hatton (1955) reported that ascorbic acid is a respiratory substrate and is likely to be lost during storage. The present findings were supported by Adisa, (1986) ,who noticed that the ascorbic acid content of healthy pineapple gradually decreased with the increase in storage period. However the highest amount of ascorbic acid was found in least matured fruits (15.28 mg/100g) than the fully matured fruits (11.81mg/100g) during storage. Similar findings are reported in citrus fruits by Nagy (1980), who found that the immature citrus fruits contained the highest concentration of vitamin C, whereas, ripe fruits contained the least.

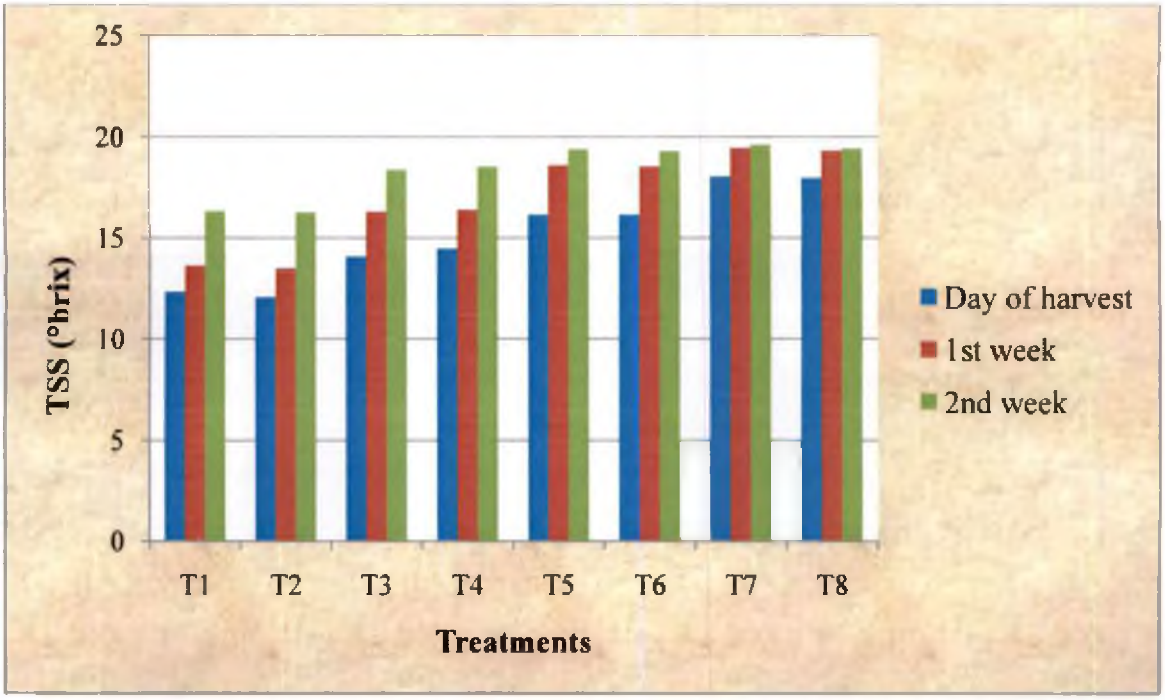


Fig. 1. Effect of method and stage of harvest on TSS of fruits

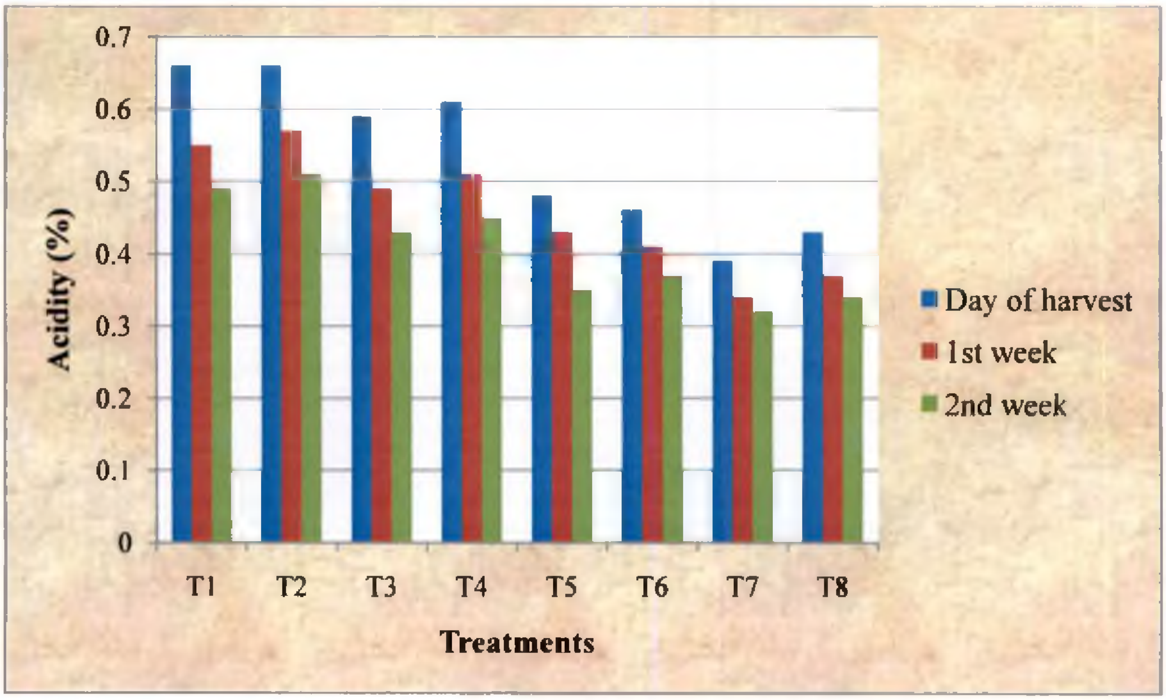


Fig. 2. Effect of method and stage of harvest on acidity of fruits

5.1.2.4 Sugars

Sugar includes reducing, non- reducing and total sugar. Significant difference was observed for sugars. There was decreasing trend in reducing sugar whereas total and non-reducing sugar showed an increasing trend the rate of which decreased gradually (Fig.3). Kapse *et.al.* (1977), reported that the sugars increased rapidly in fruits stored at room temperature and then decreased. This may be due to the conversion of starch to sugar during ripening and later sugar decrease due to senescence, as sugar was utilized as respiratory substrate. The hydrolysis of starch, yielding mono and disaccharides could be one of the reasons for increase in TSS and total sugars. On complete hydrolysis of starch, no further increase in TSS and sugar occurs, and consequently a decline in these parameters is predictable as they are the primary substrates for respiration (Wills *et al.*, 1980). The increase in total sugar associated with the advance of storage period is usually due to break down of polysaccharides and conversion of starch into sugar (Wills *et al.*, 1989).

5.1.3 Sensory evaluation

Sensory qualities are very important from the consumer's point of view. It depends on characters like colour, taste, flavour and texture. Overall acceptability of any fruit is based on all these characters. The overall sensory score and mean rank was highest for T_5 (25-50% eyes changed to yellow harvested by retaining peduncle) during first week of storage and T_3 (0-25% eyes changed to yellow harvested by retaining peduncle) during second week of storage (Fig.4 & 5).

Effect of harvest maturity on fruit taste and flavour is due to rapid increase in sugar accumulation during the first stages of ripening as a result of organic acid conversion to sugars (Wills *et al.*, 1998). Ersoy *et al.*, (2007) reported that sweetness which is an important indicator of fruit quality is highly correlated with ripeness in most fruits. According to Ishtiaq *et al.* (2010), yellowness of the fruit is accompanied by a progressive sweetness of the fruit pulp due to the formation of sugars.

It was clearly evident from the results that the stage of maturity at harvest is one of the key factors determining postharvest quality and shelf life. Among the

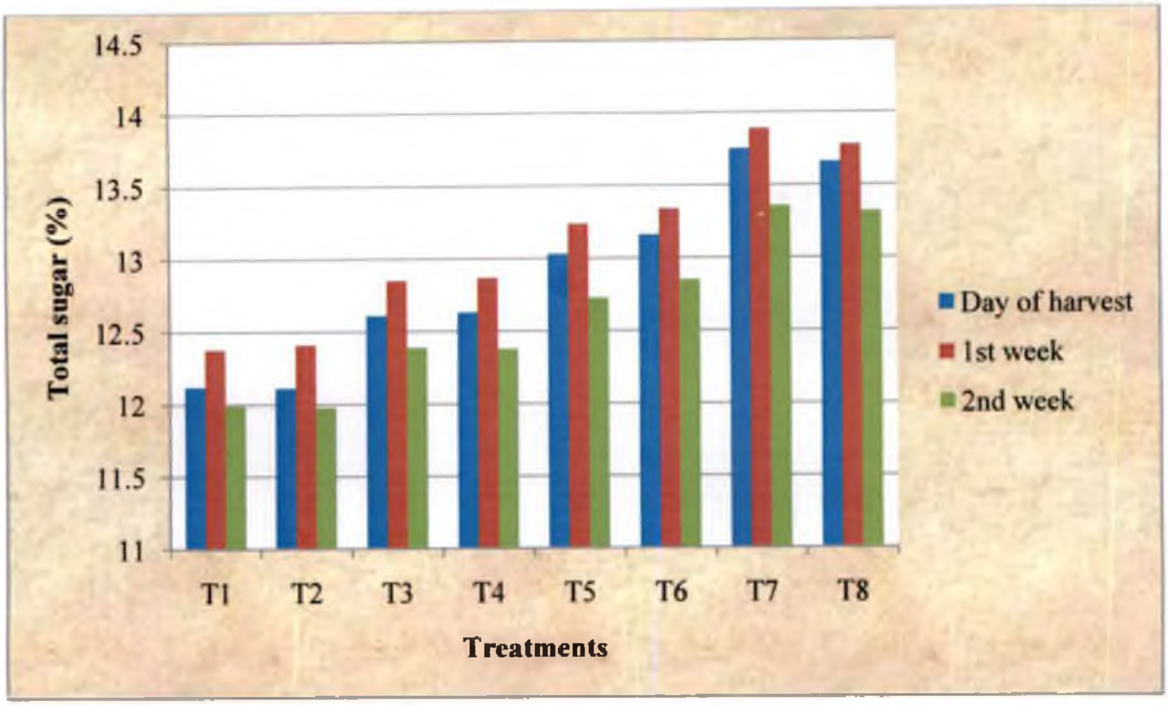


Fig. 3. Effect of method and stage of harvest on total sugar of fruits

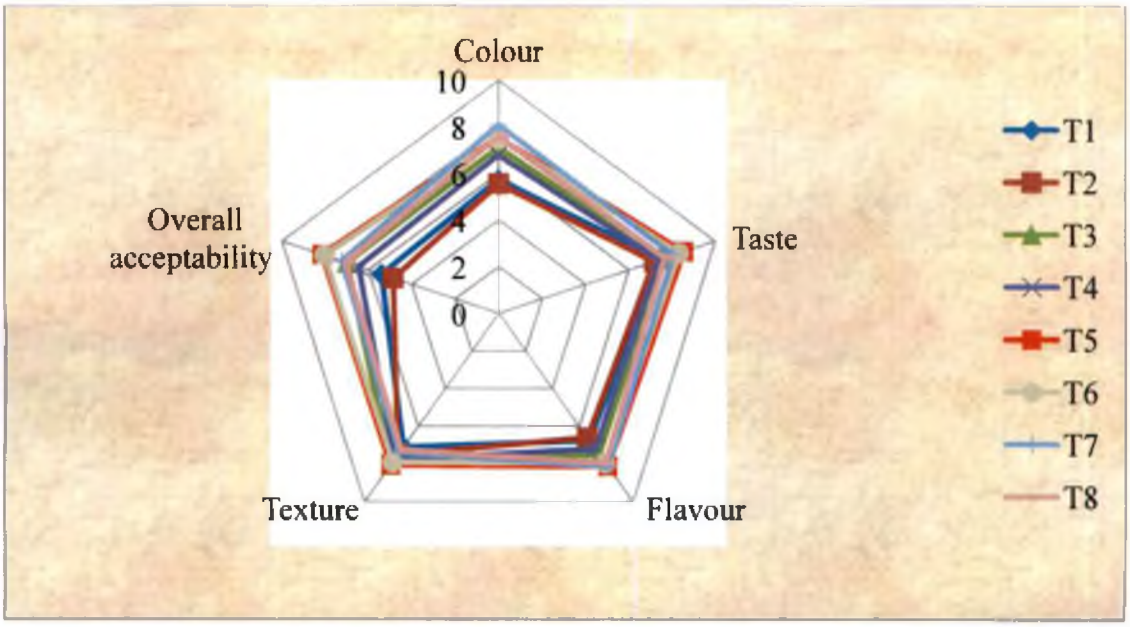


Fig.4. Effect of method and stage of harvest on sensory attributes of fruit during 1st week of storage

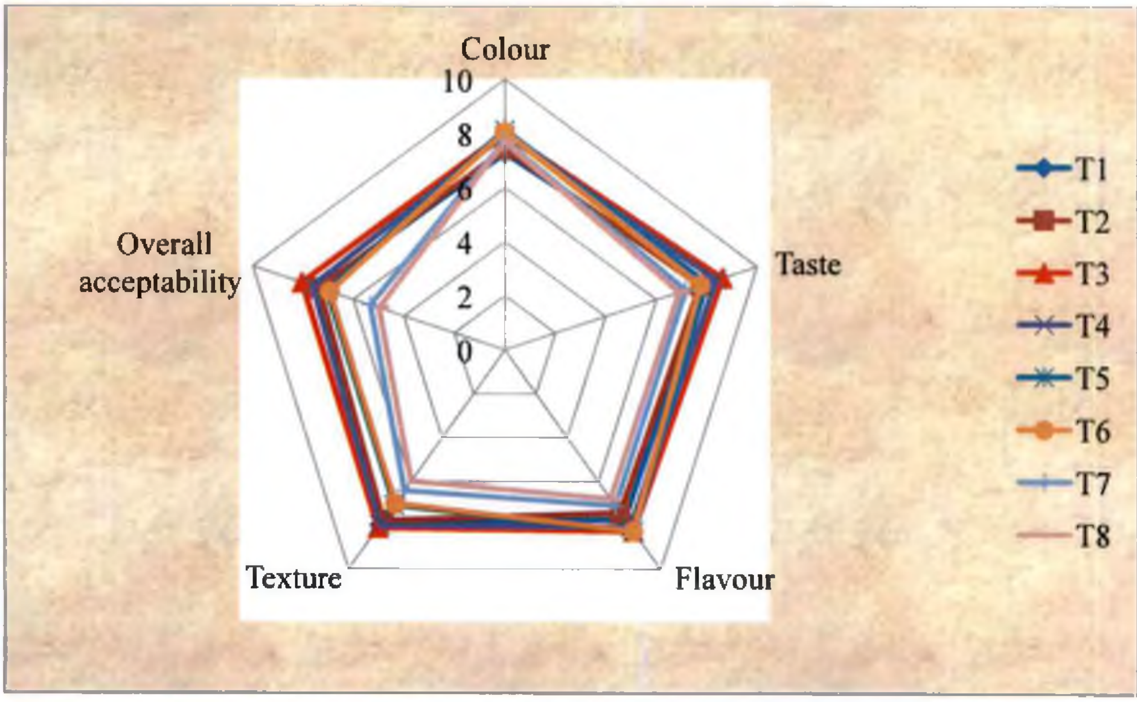


Fig.5. Effect of method and stage of harvest on sensory attributes of fruit during 2nd week of storage

eight treatments, biochemical constituents were better for fruits harvested when 50-100% eye colour changed to yellow, whereas fruits harvested at 0-25% eyes turned yellow by retaining peduncle was having better keeping and sensory quality. Hence the fruits harvested at 0-25% eyes turned yellow by retaining peduncle were used for further storage studies.

5.2 Evaluation of storage method

Method of storage after harvest is also a factor determining postharvest quality and shelf life of the fruit. Different storage methods like heaping and covering with 150 GSM silpaulin, stacking fruits vertically with crown downward, stacking fruits vertically with crown upward and storing in paper cartons were studied. Posture of fruits and vegetables in storage also has significant effect on their postharvest freshness (Usushizaki *et al.*, 1987).

5.2.1 Physical attributes

Physical attributes includes PLW, blackening/browning, incidence of spoilage and shelf life.

PLW was lowest for the fruits stored vertically with crown downward position (9.33%) and highest (10.18 %) for fruits heaped and covered with silpaulin (Fig.6). Fruit weight loss during storage is attributed to loss of moisture and reserve food materials by evapo-transpiration and respiration respectively. Air spaces present around the stored produce helps to reduce pressure causing the water loss from fresh produce. The faster the air movement faster will be the rate of deterioration. So well designed stacking pattern can contribute to the controlled air flow through the produce (Kumar *et al.*, 2009).

Blackening/browning was found highest in fruits heaped and covered with silpaulin which may be due to high temperature build up in the produce. Peduncle damage is observed in fruits stacked vertically with crown upwards, this may be due to the increase pressure on the peduncle. Least browning was noticed in fruits stacked vertically with crown down.

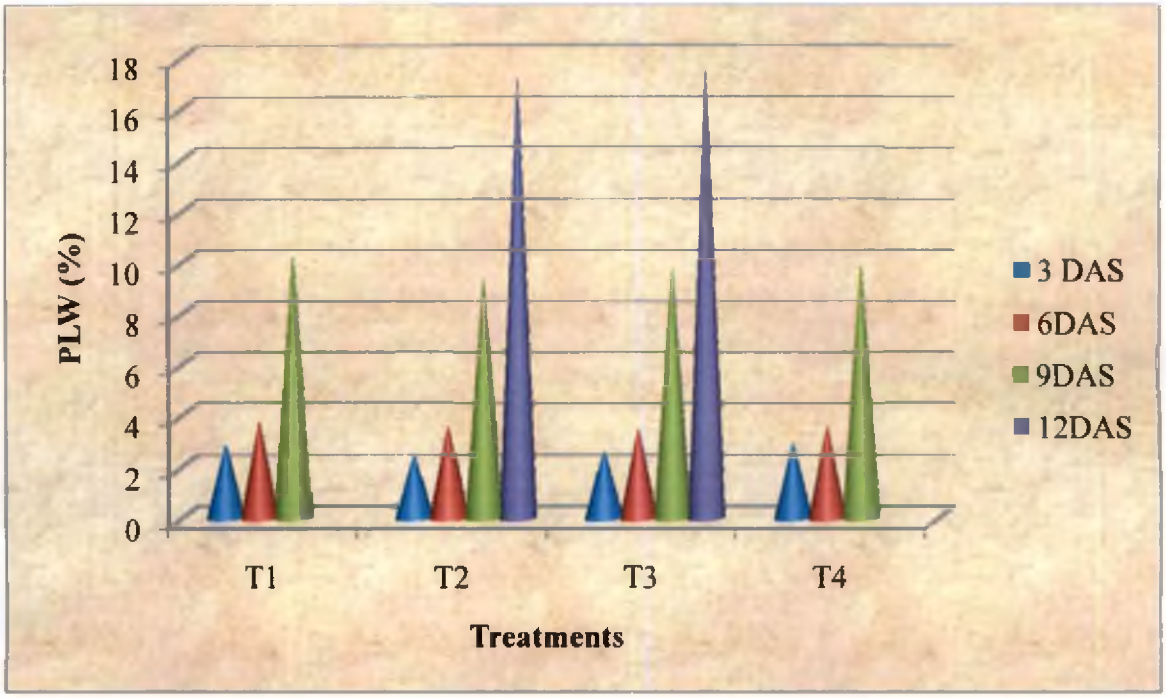


Fig.6. Effect of storage method on PLW (%)

Spoilage of fruits is attributed to factors like maturity at stage of harvest, method of harvest and storage, attack by pathogens like bacteria, fungi and yeast. Fruits stored by heaping and covered with silpaulin spoiled faster followed by fruits stored in cartons. This may be due to the high rate of fermentation. Spoilage of the peduncle in fruits stored vertically with crown up was noticed. Least spoilage was found in fruits stored vertically with crown down. This may be due to the cushioning effect provided by the crown.

Shelf life of the fruits is calculated as the number of days till the fruits remained marketable. Maximum keeping quality was noted in fruits kept vertically with crown down as 13 days and least in fruits heaped and covered with silpaulin as 9 days.

5.2.2 Chemical constituents

Chemical constituents of fruits include TSS, acidity, ascorbic acid and sugars.

TSS increased with increasing storage period for all the treatments. Significant variation was not observed for TSS. However percentage increase in TSS showed significant difference and was found to be highest for fruits stacked vertically with crown down and the high TSS may be due to less use of sugars for respiration. Values for TSS ranged from 16.1 to 18.17.

Acidity decreased with storage period and was found to be non-significant. The lowest acidity was found in fruits stacked vertically with crown upward (0.36%) whereas percentage decrease in acidity was highest (22.6%) in fruits stacked vertically with crown down.

Ascorbic acid was also found to be decreasing and non-significant during storage. Ascorbic acid ranged from 8.85 to 12.5mg/100g of fruit.

Sugars differed significantly during storage. The highest amount of sugar (12.44%) was observed in fruits stored vertically by crown down at the end of storage. It was reported by Usushizaki *et al.*, (1987) that changes in starch and sugar contents with storage differ in various postures. Similar findings were reported in guava by Siddiqui *et al.* (1991) where the guava fruits kept by pedicel end vertically upward had higher amount of SSC (Soluble Solid Concentration) and sugars.

5.2.3 Sensory evaluation

Sensory evaluation for colour, taste, flavour, texture and overall acceptability was carried out. The selected parameters to predict eating quality in pineapples are TSS (%), titrable acidity, TSS/acid ratio, pH, colour and translucency (Smith, 1988). During first week of storage the maximum score for overall acceptability was recorded for T_4 (fruits stored in paper cartons) and during second week for T_2 (fruits stacked vertically with crown downwards) (Fig 7 & 8).The low PLW, high TSS and maintenance of other quality characteristics may be responsible for the high organoleptic rating of the fruits kept vertically with crown down.

Among the different methods of storage, longest shelf life, highest TSS, sugar and better sensory quality was noticed in T_2 (stacking fruits vertically with crown downwards) and hence was used for further studies.

5.3 Post-harvest treatment studies

Fruits after harvest if not managed properly losses its shelf life at faster rate resulting in fruit spoilage before it reaches the ultimate user. Contamination of the fruits and vegetables by pathogens can occur anywhere during production, harvesting, postharvest handling, storage, processing and transport (Gorny, 2005). Various physical and chemical treatments have been practised to extend the storage life of fruits and vegetables. Keeping this in view, work was undertaken to find out suitable postharvest treatments for pineapple. Treatments like immersing in cold water, 1% acetic acid, luke warm chlorinated water, alum and hot water dip were carried out and the results are discussed below.

5.3.1 Physiological loss in weight

Among the different postharvest treatments lowest PLW (23.23%) was observed in fruits dipped in hot water (50°C for 1 min) whereas in control fruits high PLW (32.87%) was observed (Fig.9). Similar results were obtained by Waskar., 2005. He reported that the lowest rate of increase in PLW (%) in hot water dip could

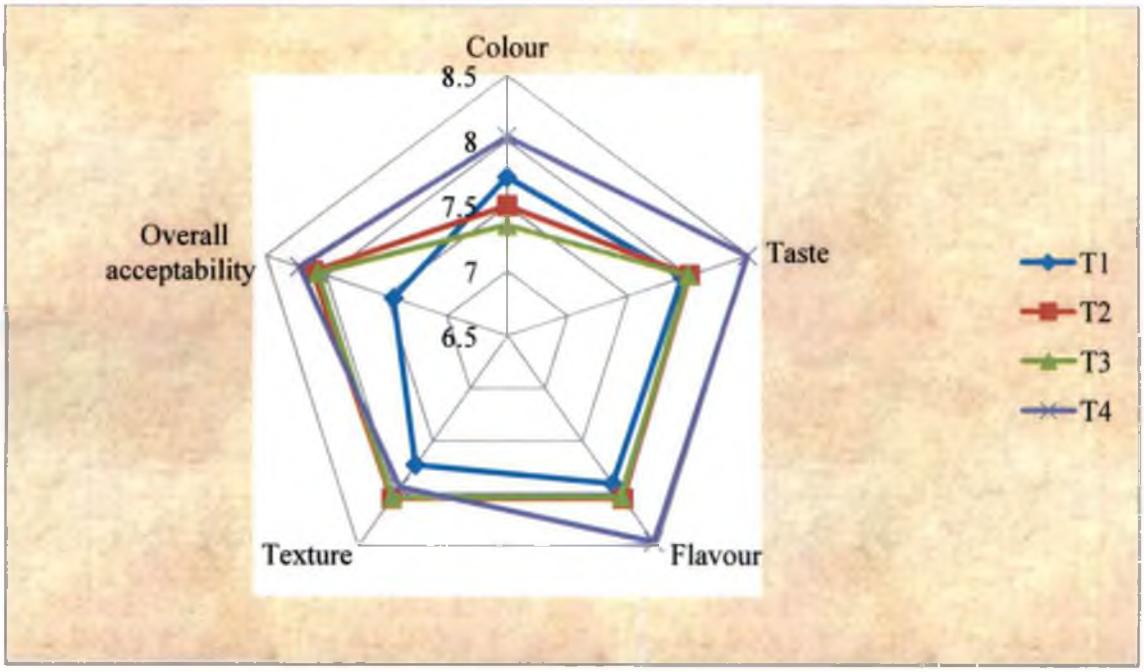


Fig.7. Effect of storage methods on sensory attributes of fruits during 1st week of storage

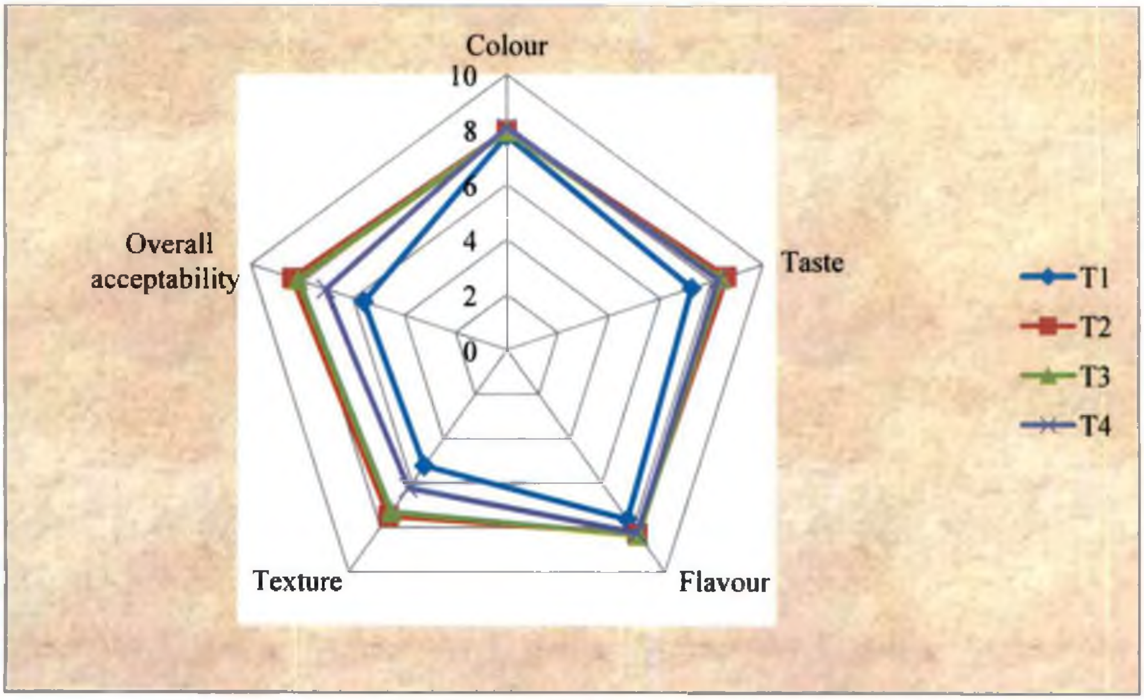


Fig.8. Effect of storage methods on sensory attributes of fruit during 2nd week of storage

be due to maintaining firmness, delaying the spoilage and thus lowering the rate of ripening.

5.3.2 Total microbial load

The minimum microbial load for bacterial colonies (10.78×10^6 CFU/ml), fungal colonies (3.63×10^3 CFU/ml) and yeast colonies (2.53×10^3 CFU/ml) was noted in hot water dipped fruits followed by alum treated fruits as 12.35×10^6 CFU/ml,6.23×10^3 CFU/ml and 2.98×10^3 CFU/ml for bacterial, fungal and yeast colonies respectively. The maximum load was noted in control fruits as 30.28×10^6 CFU/ml, 8.48×10^3 CFU/ml and 5.63×10^3 CFU/ml for bacterial, fungal and yeast colonies. Similar results were obtained in mango by Sopee and Sangchote (2005) who reported that the heat treatments reduced viability and delayed the growth of the fungus and consequently reduced disease development. Vandevivere and Kirchman (1993) reported that the efficacy of the warm water treatment may be that the adhesive extracellular hydrocolloids produced by bacteria to enhance their binding to surface are dissolved by heated water.

5.3.3 Shelf life

Maximum shelf life was observed in fruits treated with hot water as 14.5 days compared to control as 13 days. This may be due to low PLW and microbial load during storage of fruits dipped in hot water at 50°C for 1 min.

Among the treatments the least PLW, microbial load and longest postharvest life was noticed in T_5 (fruits treated by hot water dip) and hence this postharvest treatment was used for storage temperature studies.

5.4 Optimization of storage temperature

Horticultural commodities have less postharvest life when kept at ambient conditions. Temperature is one of the most influential factors in fruit storage. All biological processes are controlled by temperature and thus fruit quality and ripening are strongly affected by storage temperature (Fuchs *et al.*, 1995). Low temperature storage can most effectively extend shelf life and reduce postharvest losses by arresting metabolic break down and fruit quality deterioration. Therefore,

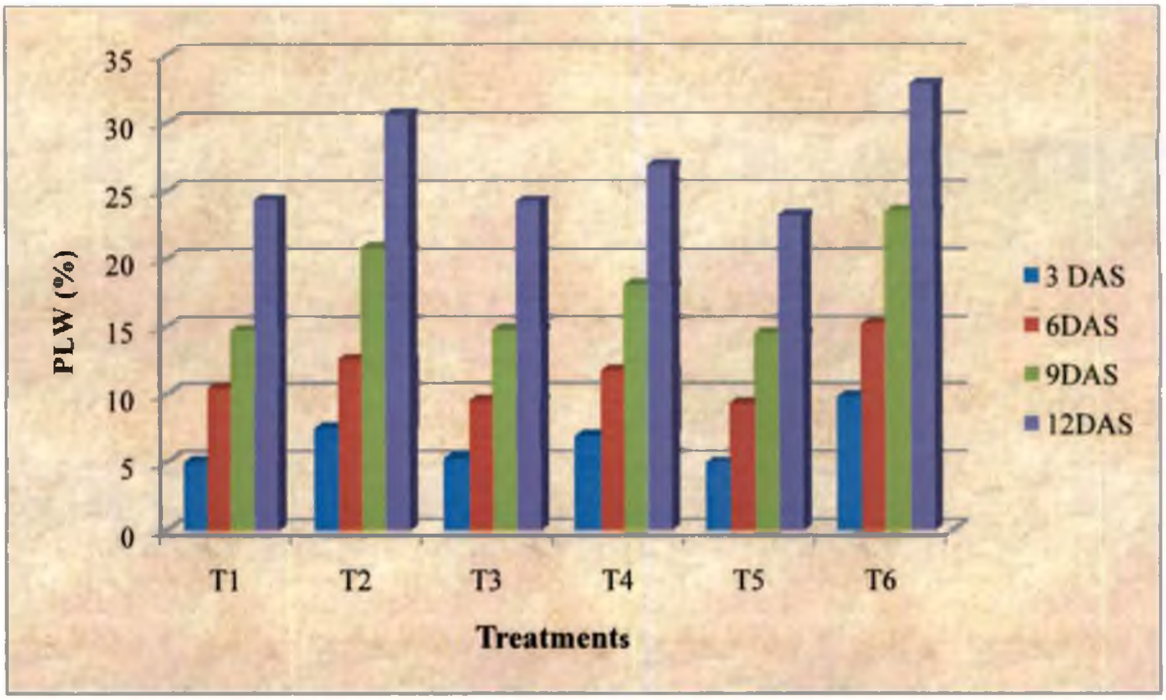


Fig.9. Effect of postharvest treatments on PLW (%)

an attempt has been made to study the effect of different storage temperatures on the physical and biochemical qualities of the pineapple. The storage temperatures studied were 8±2°C, 14±2°C, 20±2°C, 26±2°C and ambient temperature.

5.4.1 Physiological loss in weight

Temperature has impact on physiological loss in weight. PLW was found lowest for the fruits stored at low temperature (8±2°C). Similar results were obtained by Dhar *et al.* (2008) who observed that the fruits stored at low temperature were found to be fresher probably due to less moisture loss from them. Lester (1988) reported that during low temperature storage, fruit water loss decreases especially in the lowest temperatures. Tasdelen and Bayindirli (1998) reported that cold stored tomato fruits had a low weight loss due to temperature effects on vapour pressure difference and increased water retention. Waskar (2005) reported similar findings in mango fruits PLW was at a slower rate in cool chamber stored mango fruits than room temperature stored fruits and this reduction in weight loss was due to reduction in respiration as well as transpiration rates at lower temperatures.

5.4.2 Blackening/ browning

Although low temperature storage is the most effective method to maintain the quality of fruit, it can be detrimental to cold-sensitive tropical commodities due to chilling injury. Chilling injury symptoms evidenced by drying and discoloration of crown leaves, browning and dulling of yellow fruit and internal flesh browning was observed in low temperature storage of pineapple. These findings were supported by (Lim, 1985; Paull and Rohrbach, 1985). The symptoms were less prevalent in fruits stored at 8± 2°C. The intensity of internal browning symptoms increased with increasing temperature whereas there was no internal browning in fruits stored at ambient temperature. This result is supported by works done by Hong *et al.*, 2013. They found that there was a relation between increasing IB symptom and temperature increase and the IB is directly related to polyphenol oxidase activity. Pusittigul et al. (2012) reported that the changes in endogenous ABA (abscissic acid) concentrations were ascribed to stress response and the increase in total endogenous GA (giberrelic acid) were associated with the increased

IB and PPO activity. It was also reported by Paull and Rohrbach (1985) that there was faster development of chilling injury symptoms in pineapple stored at 20-25°C. Weeraheva and Adhikaram (2005) reported that in Mauritius variety PPO activity increased over ten times of its initial activity during cold storage and this increase coincides with onset of IB symptoms. They also reported that increased acid levels in cv. Mauritius might be an important factor in the development of increased internal browning. Exposure of pineapple to temperature below 7°C results in chilling injury (Kumar *et al.*, 2009). The symptoms include dull green colour when ripen, water soaked flesh, darkening of the core tissue, increased susceptibility to decay, wilting and discolouration of crown leaves. From the above said statements and the results of the present experiment, it was evident that the temperature of 8± 2°C is ideal for storage of pineapple fruits without chilling injury. Temperature above and below this temperature range may cause chilling injury and hence affect marketability of the fruits.

Amiot *et al* (1997) also found a possible involvement of peroxidases in the IB of pineapple. Higher activity of peroxidase was found in fruits stored at > 10°C than those stored at < 10°C (Van Lelyveld and De Bruyn , 1977).

5.4.3 Incidence of spoilage and shelf life

The fruits kept in cold storage showed least spoilage except for the IB. Fruits kept at ambient temperature showed maximum spoilage and least shelf life. The fruits kept at 8± 2°C showed maximum shelf life (33 days) whereas fruits stored at ambient condition had least shelf life of 14.5 days. So an additional 18.5 days storage life is attained by cold storage at 8± 2°C. Decrease in senescence rate with storage at low temperature due to decrease in respiration, ethylene production, water loss and less sensitivity of fruit tissue to ethylene effect leads to quality retention at lowest temperature (Wills *et al.*, 1989). Low temperature prolongs the shelf life probably due to the reduction of various gases (O_2, CO_2) exchange from the inner and outer atmosphere as well as slowing down the hydrolysis process (Uddin and Hossain, 1993). An increase in temperature causes an increase in the rate of natural break down of fruits as food reserves and water content become depleted. The cooling of produce will extend its life by slowing the rate of break down (Kumar *et* *al*., 2009). It also slows the growth of pathogenic fungi, which cause spoilage of fruits in storage.

5.4.4 Biochemical parameters

TSS was found to increase during initial period of storage and then decreased with advancement of storage (Fig.10). Acidity decreased in the initial stages of storage and then increased during the storage (Fig 11). The highest TSS was found in fruits stored at 8± 2°C as 18.3°brix whereas lowest acidity (0.44%) was noted in fruits stored at ambient temperature. Titrable acidity reduced as storage temperature increased. The acidity was low in fruits stored at room temperature whereas it was high in fruits stored at low temperature as the respiration rate was arrested to the minimum at low temperature (Kapse *et al*., 1977). Organic acids are substrates of respiration. The rate of metabolic processes like respiration is reduced by storage at low temperature and this may account for the high acidity in fruits stored at 8±2°C. Pailly *et al*. (2004) obtained similar results with grape fruit (*Citrus paradise*) where fruits stored at 6° C had higher TA than those stored at 10° C.

The highest ascorbic acid content (19.79mg/100g) was observed in fruits stored at 8± 2°C during entire period of storage. Ascorbic acid decreased during storage to a higher extent at the highest storage temperature used (Fig.12), probably due to higher requirement of antioxidant scavenging due to higher respiration rate (Souto *et al*., 2004). This observation corresponds with previous studies which found that there was a gradual decrease in ascorbic acid content of pineapple fruit as the storage temperature increased (Adisa, 1986). He also reported that the ascorbic acid in fruits is sensitive to storage temperature or duration and its degradation is enhanced by adverse handling and storage conditions such as higher temperatures, low relative humidity, physical damage and chilling injury.

Sugar was found to decrease during storage, however the rate of decrease was non-significant. Experiment conducted by Sanchez *et al*. (2012) concluded that sucrose content decreased in pineapple fruits when stored at 8 and 20°C. Under low temperature condition the sugar content decreased slowly because there is suppression in rate of respiration and enzyme activity.

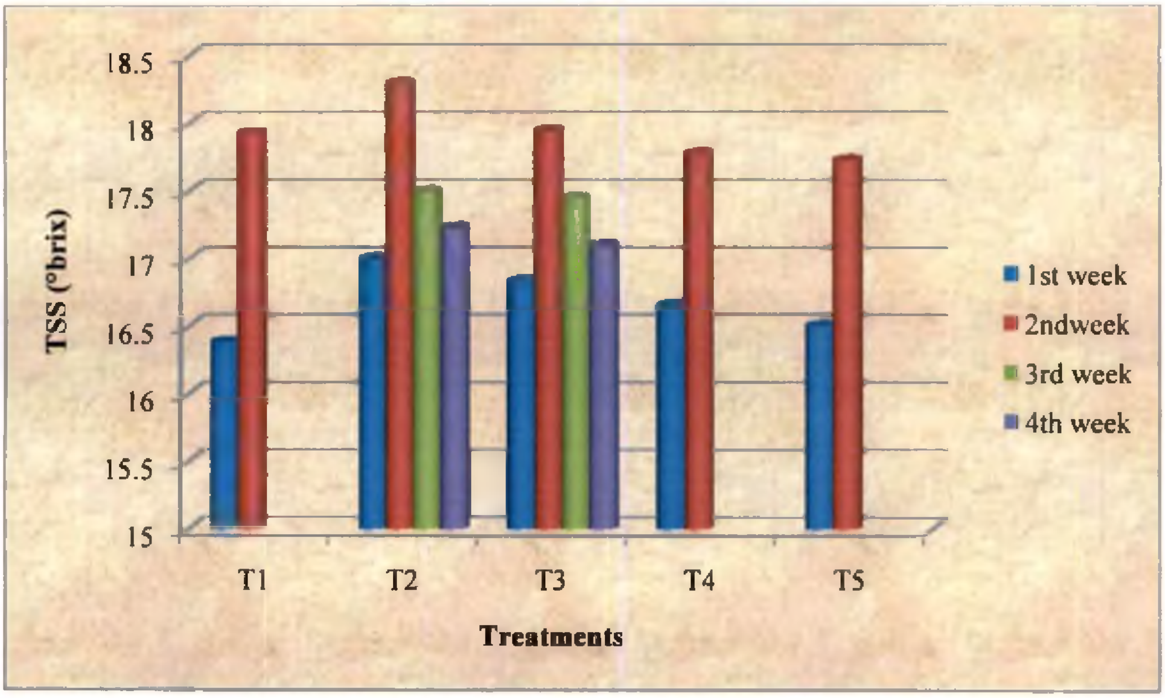


Fig.10. Effect of storage temperature on TSS of fruits

5.4.5 Sensory evaluation

Sensory evaluation during the four weeks of storage was carried out. The fruit stored at 8±2°C was observed to be superior in sensory quality compared to other treatments during the entire period of storage (Fig. 13 &14). This may be due to retaining of high TSS and low PLW during storage at low temperature.

Among the treatments maximum shelf life, highest TSS and ascorbic acid content and better sensory quality were observed in T_2 (cold storage: 8± 2 ^{0}C). The ideal temperature to avoid chilling injury in pineapple is 8±2°C. The fruits kept above and below this temperature were having less postharvest life.

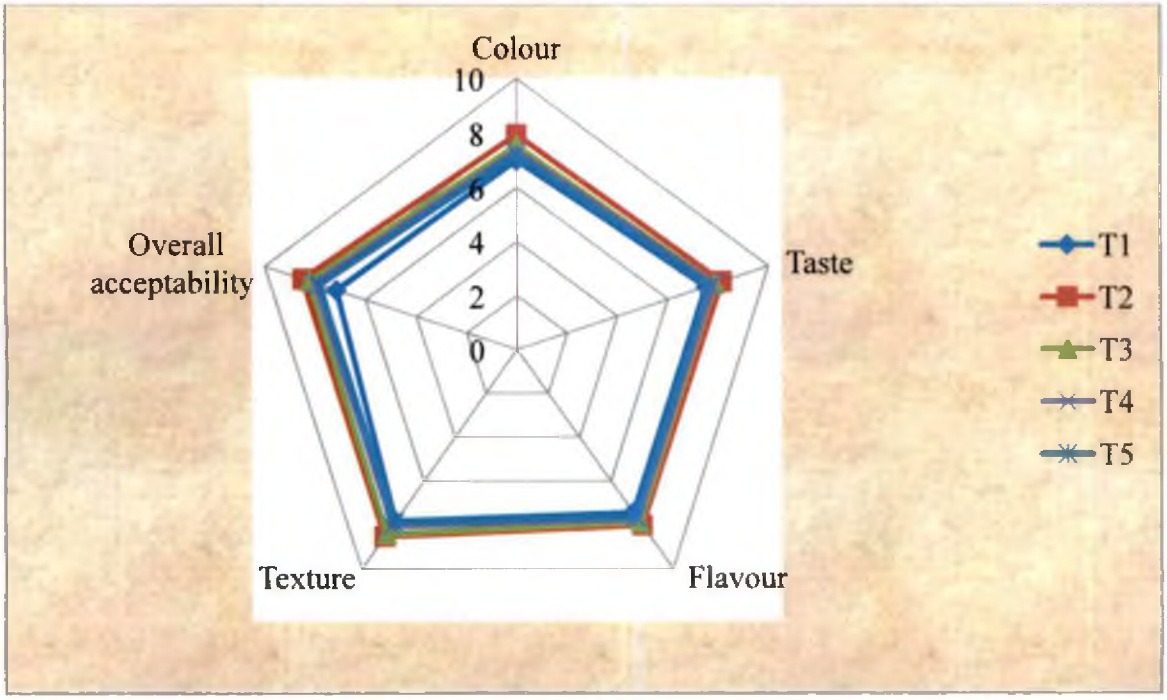


Fig.13. Effect of storage temperature on sensory qualities of fruit during 1st week of storage

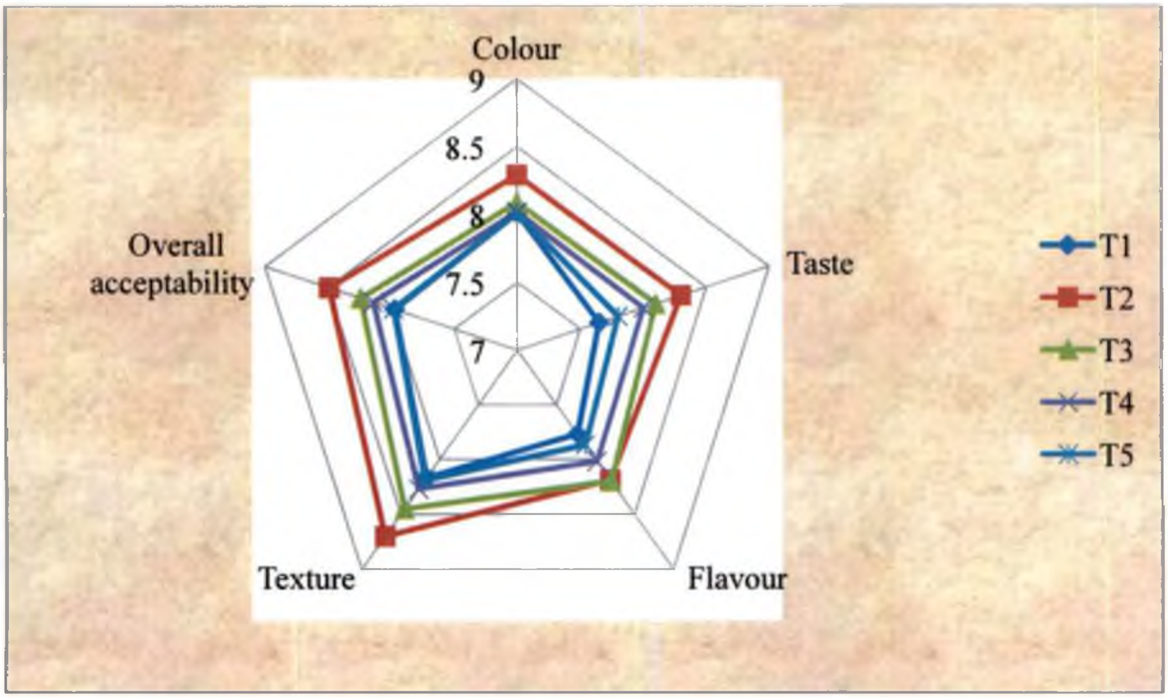


Fig.14. Effect of storage temperature on sensory qualities of fruit during 2nd week of storage

POSTHARVEST PRACTICES FOR PINEAPPLE

Harvesting pineapple fruits when 0-25% eye colour changes to yellow by retaining peduncle

→ Trim/cut the peduncle with a sharp knife

→ Sorting of the fruits

→ Sorted fruits are dipped in hot water at 50°C for 1 min

→ Store the hot water dipped pineapple by keeping crown in downward manner at cold storage of 8±2°C

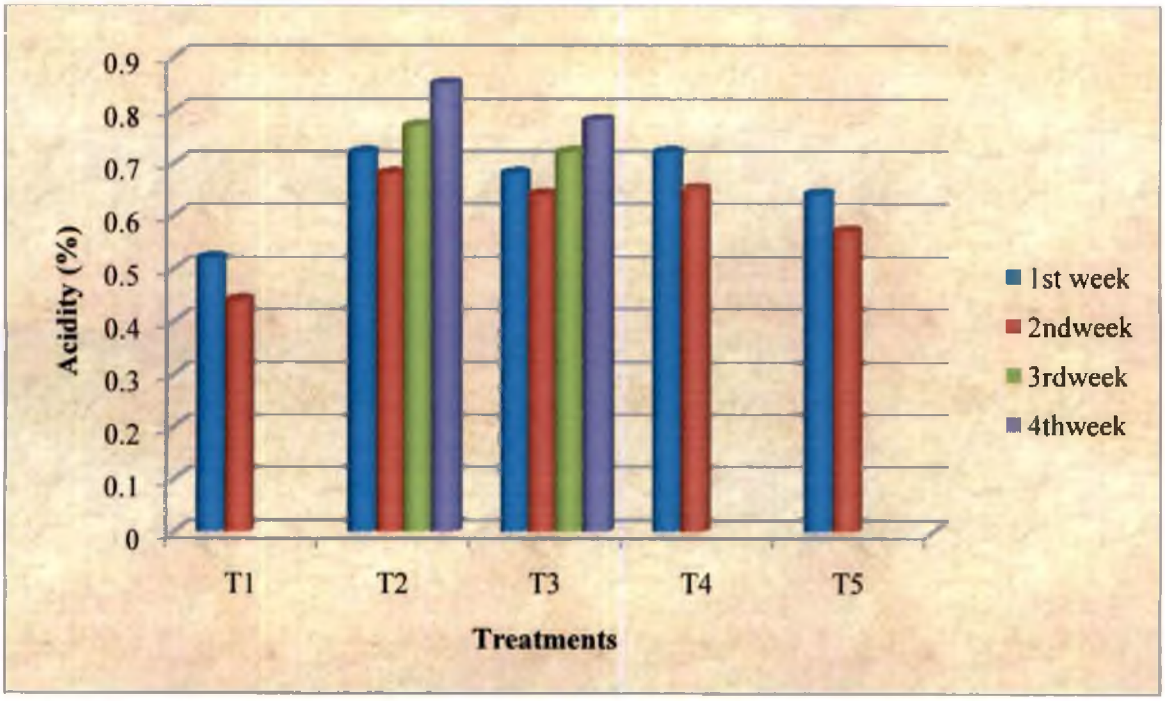


Fig.11. Effect of storage temperature on acidity of fruits

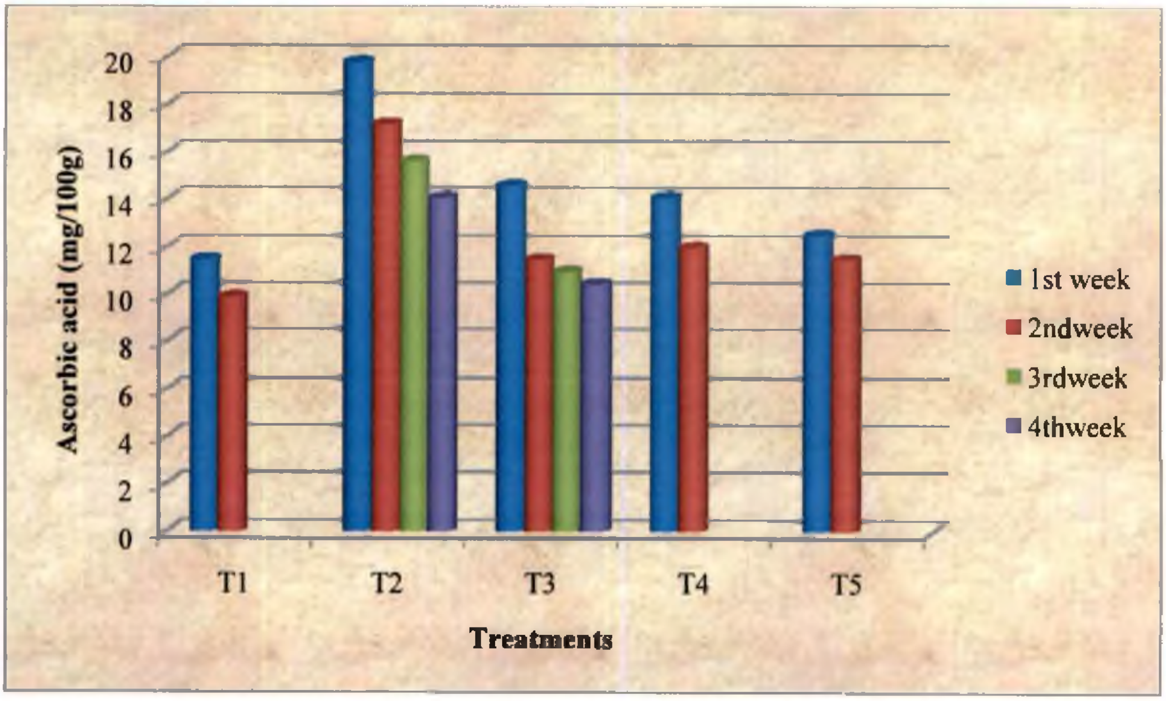


Fig.12. Effect of storage temperature on ascorbic acid content of fruits

SUMMARY

6. SUMMARY

Studies on postharvest management in pineapple (*Ananas comosus* (L.) Merr.) were carried out in the Department of Processing Technology, College of Horticulture, Vellanikkara during 2011-13. The main objectives were to standardize the harvesting stage, storage method, postharvest treatments and storage temperature in pineapple. The study was conducted to observe the physical, biochemical and sensory changes during postharvest period and to standardize methods to enhance the shelf life of the fruit.

The physical and biochemical changes during storage of pineapple fruits harvested at four stages of maturity with and without peduncle were recorded. The maturity stages are mature green, 25% yellow eye colour, 25-50% yellow eye colour and 50-100% yellow eye colour.

The fruits harvested by retaining peduncle showed less spoilage and better quality than the fruits harvested without peduncle. The least incidence of spoilage and maximum shelf life was observed for fruits harvested when 0-25% of eyes turned to yellow colour. TSS was found to increase during storage period and percentage increase was highest for fruits harvested at this stage. Acidity and ascorbic acid showed decreasing trend. During storage sensory characters were also found to be better in this treatment. The Physiological Loss in Weight (PLW) was less when fruits were harvested with peduncle and more than 25% eyes were yellow. Spoilage of fruits was more when harvesting was done at advanced stages of maturity.

Pineapple fruits harvested with peduncle and 0-25% yellow eyes were used for evaluating the method of storage. Different storage methods for pineapple like heaping and covering with silpaulin (150 GSM), stacking fruits vertically with crown downwards, stacking fruits vertically with crown upwards and storing in paper cartons were carried out. Stacking the fruits vertically with crown down was found to be the best method of storage under ambient conditions. Higher TSS, sugar and better sensory quality were observed for fruits stacked vertically by crown down at the end of storage. The crown provided a cushioning effect to the fruits and it showed lowest PLW and maximum shelf life.

The effect of different postharvest treatments on enhancing the shelf lif and reducing microbial load on pineapple fruits were evaluated. Postharvest treatments like immersing in cold water, 1% acetic acid, luke warm chlorinated water, alum and hot water dip were given to prolong storage period without loss of quality. Among the different treatments, hot water dip treatment (50°C for 1 min) was found to be effective in reducing PLW and microbial load in the fruits compared to all other treatments followed by alum treatment. Maximum shelf life was recorded for fruits treated with hot water.

Low temperature storage is an effective means for keeping horticultural commodities at high post-storage quality. Hot water dipped fruits stored at different temperatures *viz.*, 8±2°C, 14±2° C, 20±2° C, 26±2° C and ambient condition were compared for physical, biochemical and sensory characters. The fruits stored at 8±2°C had longest shelf life while those stored at ambient condition had shortest shelf life. The low temperature maintained the quality of the fruits for longer period. Biochemical and sensory qualities were also found to be better in fruits stored at 8±2°C.

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* originals not seen

APPENDICES

APPENDIX I

Score card for sensory evaluation of pineapple

9 point hedonic scale

Product code	**Colour**	**Taste**	**Flavour**	**Texture**	**Overall acceptability**

Note: You are provided with the samples of pineapple fruit and you are requested to rank them according to the scale given below as per your liking

Scale:

9 Like Extremely
8 Like Very Much
7 Like moderately
6 Like slightly
5 Neither Like nor Dislike
4 Dislike Slightly
3 Dislike Moderately
2 Dislike Very Much
1 Dislike Extremely

Date: **Name:**

Signature:

APPENDIX II

Nutrient composition of media

1. Nutrient Agar Media (for Bacteria)

Beef extract	3 g
Peptone	5 g
Sodium chloride	5 g
Agar	18 g
Distilled water	1000 ml
p^H	6.8-7.2

2. Potato Dextrose Agar Media (for Fungi)

Peeled potatoes	250 g
Dextrose	20 g
Agar	18 g
Distilled water	1000 ml
p^H	5.6

3. Sabouraud Media (for Yeast)

Mycological peptone	10g
Dextrose	40g
Agar	15g
Distilled water	1000 ml
p^H	5.6

APPENDIX III

Mean rank scores for the effect of method and stage of harvest on sensory attributes of fruit

1. 1st week

Treatments	Colour	Taste	Flavour	Texture	Overall acceptability
T_1	2.10	3.17	2.27	2.90	2.10
T_2	1.60	2.13	1.83	3.87	1.33
T_3	4.60	3.93	4.30	5.83	4.87
T_4	3.50	3.20	3.70	4.53	3.57
T_5	5.77	7.40	6.10	5.83	7.37
T_6	5.43	6.50	5.77	5.47	6.87
T_7	7.27	5.63	6.40	3.87	5.23
T_8	5.73	4.03	5.63	3.70	4.67
Kendall's coefficient	0.669**	0.606**	0.542**	0.216**	0.765**

2. 2nd week

Treatments	Colour	Taste	Flavour	Texture	Overall acceptability
T_1	2.37	4.73	4.17	6.50	5.27
T_2	3.07	4.13	3.13	5.63	4.90
T_3	5.43	7.20	6.33	6.70	7.17
T_4	5.37	6.67	5.50	6.20	6.07
T_5	6.07	4.87	6.27	3.70	4.67
T_6	5.50	4.23	6.03	3.47	4.07
T_7	4.30	2.57	2.53	2.10	2.33
T_8	3.90	1.60	2.03	1.70	1.53
Kendall's coefficient	0.321**	0.622**	0.543**	0.707**	0.590**

** - significant at 1% level

APPENDIX IV

Mean rank scores for the effect of storage methods on sensory attributes of fruit

1. 1st week

Treatment	Colour	Taste	Flavour	Texture	Overall acceptability
T_1	2.67	2.30	2.03	2.17	1.77
T_2	2.07	2.30	2.47	2.77	2.83
T_3	1.87	2.17	2.47	2.70	2.50
T_4	3.40	3.23	3.03	2.37	2.90
Kendall's coefficient	0.324**	0.166	0.110	0.051	0.184*

2. 2nd week

Treatment	Colour	Taste	Flavour	Texture	Overall acceptability
T_1	2.03	1.13	1.57	1.30	1.17
T_2	2.63	3.30	2.87	3.60	3.73
T_3	2.47	2.77	3.23	3.00	3.07
T_4	2.87	2.80	2.33	2.10	2.03
Kendall's coefficient	0.082	0.593**	0.347**	0.651**	0.794**

**- significant at 1% level

*- significant at 5% level

APPENDIX V

Mean rank scores for the effect of storage temperature on sensory qualities of fruit

1. 1st week

Treatment	Colour	Taste	Flavour	Texture	Overall acceptability
T_1	1.43	1.80	1.63	1.63	1.03
T_2	4.73	4.57	4.00	4.40	4.93
T_3	3.50	3.17	3.57	4.03	3.87
T_4	3.07	3.27	3.13	2.93	3.07
T_5	2.27	2.20	2.67	2.00	2.10
Kendall's coefficient	0.653**	0.537**	0.362**	0.623**	0.952**

2. 2nd week

Treatment	Colour	Taste	Flavour	Texture	Overall acceptability
T_1	2.57	1.60	1.97	2.10	2.03
T_2	4.07	4.53	3.80	4.60	4.60
T_3	2.77	3.70	3.77	3.60	3.53
T_4	2.53	3.00	3.17	2.73	3.13
T_5	3.07	2.17	2.30	1.97	1.70
Kendall's coefficient	0.172*	0.632**	0.313**	0.549**	0.616**

3. 3rd week

Treatment	Colour	Taste	Flavour	Texture	Overall acceptability
T_2	1.70	1.83	1.50	1.70	1.93
T_3	1.30	1.17	1.50	1.30	1.07
Kendall's coefficient	0.240	0.556**	0.000	0.200	0.867**

4. 4th week

Treatment	Colour	Taste	Flavour	Texture	Overall acceptability
T_2	1.90	1.87	1.87	2.00	1.93
T_3	1.10	1.13	1.13	1.00	1.07
Kendall's coefficient	0.800**	0.621**	0.621**	1.000**	0.751**

** - significant at 1% ; * - significant at 5%

POSTHARVEST MANAGEMENT STUDIES IN PINEAPPLE (*Ananas comosus* (L.) Merr.)

By

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ABSTRACT

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ABSTRACT

The investigation on 'Postharvest management studies in pineapple (*Ananas comosus* (L.) Merr.)" was carried out at the Department of Processing Technology, College of Horticulture, Vellanikkara, Thrissur, Kerala during 2011-2013.

The physiological and biochemical changes during storage of pineapple fruits harvested with and without peduncle at four stages of maturity were recorded. The maturity stages were mature green, 0-25% eye colour yellow, 25-50% eye colour yellow, 50-100% eye colour yellow. When the fruits were harvested at green mature stage, the physiological loss in weight (PLW) was highest. Maximum shelf life (13 days) and least incidence of spoilage were observed when fruits were harvested with peduncle and 25 % of eyes changed the colour to yellow. Hence it was used for storage studies. However, better biochemical characters were recorded in fruits harvested when more than 50 % eyes changed its colour to yellow. There was an increasing trend for TSS during storage of fruits at all maturity stages, where as acidity was found to decrease.

Different storage methods like heaping and covering with silpaulin (150 GSM), stacking fruits vertically with crown downwards, stacking fruits vertically with crown upwards and storing in paper cartons were carried out and the fruits stacked vertically with crown down was found to have longest shelf life (13 days), highest TSS (18.17°brix), sugar (12.44%) and good sensory quality. The crown provided a cushioning effect to the fruits and prevented bruising and damage thereby contributing to the quality.

The effect of different postharvest treatments on enhancing the shelf life and reducing microbial load on pineapple fruits was studied. Among the different treatments, hot water dip treatment was found to be effective in reducing PLW. The hot water dip treatment was also effective in reducing the total microbial load in the fruit compared to all other treatments followed by alum treatment. The maximum shelf life (14.5 days) was recorded for fruits treated with hot water and minimum shelf life (13 days) was observed when fruits were not given any treatments.

Hot water dipped fruits were stored at different temperatures *viz.*,8±2°C, 14±2° C, 20±2° C, 26±2° C and ambient condition and were evaluated for physical, biochemical and sensory characters. The fruits stored at 8±2°C were having highest postharvest shelf life (33 days). The low temperature maintained the quality of the fruits in terms of longer period. Biochemical and sensory qualities were also found to be better in fruits stored at 8±2°C.